MODELING THE SPREAD OF THE 1918 INFLUENZA PANDEMIC IN A NEWFOUNDLAND COMMUNITY

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By
JESSICA LEA DIMKA
Dr. Lisa Sattenspiel, Dissertation Supervisor

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The undersigned, appointed by the dean of the Graduate School,

have examined the dissertation entitled

MODELING THE SPREAD OF THE 1918 INFLUENZA PANDEMIC IN A NEWFOUNDLAND COMMUNITY

Presented by Jessica Lea Dimka

A candidate for the degree of

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And hereby certify that, in their opinion, it is worthy of acceptance.

Professor Lisa Sattenspiel

Professor Gregory Blomquist

Professor Mary Shenk

Professor Enid Schatz

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Jessica Dimka

Dr. Lisa Sattenspiel, Dissertation Supervisor

ABSTRACT

Infectious disease epidemics have played and continue to play important roles in human populations. Observations of epidemic effects at the regional or global level might mask the important demographic, social, cultural and random factors that influence variation at the individual or community level. In small, traditional communities, these factors include patterns of settlement and organization, daily behaviors, and important relationships. This research applies two individual-based models to test the relative impact of these different factors on disease spread in a small study community in Newfoundland and Labrador in the early 20th century, using data from the 1918 flu pandemic.

In the agent-based model, which emphasizes mobility to important social spaces, schoolchildren drive the size and timing of epidemics. Conversely, in the social network model, which reflects important relationships among community residents, adult women frequently suppress disease spread, producing smaller and later epidemics than other demographic subgroups. These results demonstrate the importance of studying how individual behaviors and interactions influence larger epidemic patterns, and of selecting appropriate design features in models intended to increase knowledge of the system of disease spread and make public health recommendations.

CHAPTER 1 – INTRODUCTION

Concerns over the potential devastastion of infectious disease epidemics have helped fuel epidemiological research in multiple disciplines. This research has demonstrated that complex political, geographic, ecological, economic, demographic and other factors contribute to the spread of disease (see, for example, Herring and Swedlund, 2010; Karlen, 1995; McNeill, 1976). As part of this growing interest, researchers have also acknowledged the importance of studying historical epidemics, which can offer unique insights into both the mechanisms of disease spread and the short- and long-term consequences of small outbreaks, seasonal epidemics, catastrophic pandemics, and the interplay of multiple conditions or pathogens (e.g. Simonsen et al., 2011). Because of disciplinary interests in holistic approaches to human biology and culture over time, anthropologists are in an ideal position to analyze and interpret epidemiological data on multiple scales for both historical and contemporary diseases and populations.

Epidemiological research also offers opportunities to bridge sometimes discordant anthropological subfields as well as opens avenues for interdisciplinary research with other fields. One potential approach for interdisciplinary research is the application of sophisticated simulation models, which can combine methods and concepts from a variety of fields including anthropology, epidemiology, biology, mathematics, history, and computer science. Such models can incorporate a variety of data and test hypotheses related to complex, population-level phenomena that emerge from individual-level behavior and relationships. However, these methods create additional concerns about the level of required data, translation of data to model processes, identification of necessary simplifying assumptions, and other questions of design (Gilbert, 2008; Grimm and Railsback, 2005; Railsback and Grimm, 2011). These concerns can limit the usefulness of models for addressing epidemiological research questions, and so the choice of model structure and related assumptions must be made carefully.

Statement of Problem

This project developed out of and contributes to both issues discussed above, i.e. questions related to the various biological and cultural factors affecting the spread of disease, and questions about how methodological concerns affect the usefulness and accuracy of models in epidemiological research. In particular, the impacts on disease spread of household structure, daily activities, important relationships, and social institutions such as churches and schools in small, traditional communities on the island of Newfoundland are considered. The goal of this aspect of the project is to investigate whether epidemic impacts and outcomes vary among demographic subgroups based on the social/cultural roles of members of those different subgroups. The subgroups of interest are fishermen, adult women with no dependent children who participate in shore crews, mothers and dependent children, and schoolchildren. These groups reflect the majority of individuals in traditional Newfoundland communities and the primary activities in which they engaged. Based on previous literature (e.g. Chao et al., 2010; Elveback et al., 1976) and analyses of other Newfoundland communities using similar methods as those in this project, schoolchildren are hypothesized to drive epidemics and be more affected than other groups. A second hypothesis is that fisherwomen, who interact with multiple groups in different settings, will facilitate transmission, while mothers and fishermen will have less of an impact due to daily activities which often isolate them from other community members. At a broader level, this research allows for consideration of how age- and sex-related activities, including the sexual division of labor based on ecological and economic concerns, may have contributed to regional variation in the unusual age- and sex-specific outcomes generally observed during the 1918 pandemic.

To address these questions, two individual-based simulation models have been developed; both models are designed to plausibly reproduce life in an early 20th century fishing village on the island of Newfoundland around the time of the 1918 influenza pandemic. These types of models explicitly consider discrete individuals or units of analysis and so enable researchers to more easily investigate heterogeneity and random factors that might play important roles in the spread of disease, particularly in small populations. The models built for this project include an agent-based model that contains individuals who travel to important social spaces in the community, and a social network model that emphasizes important relationships between residents.

Agent-based and social network models such as these are increasingly common in epidemiological modeling research (see, for example, DeAngelis and Grimm, 2014; Lloyd-Smith et al., 2015). However, they typically require different assumptions about how interactions among individuals occur. These types of models are seldom compared against each other. Therefore, the use of these models addresses the second aspect of this research project, i.e. determining how methodological assumptions affect the application of different types of models in epidemiological research. As epidemic models are frequently used to investigate or design potential public health intervention strategies for contemporary diseases (e.g. Ciofi degli Atti et al., 2008; Das et al., 2008; Eidelson and Lustick, 2004), it is important to understand how structural assumptions can systematically affect results and thus influence the validity of “real-world” recommendations, as well as understanding of the system of disease spread in general.

Organization

This dissertation is organized into nine chapters, including this one, and four appendices. Chapters 2 through 5 are reviews of relevant scholarly literature. Chapter 2 is an overview of several leading theoretical approaches to studies of population health in anthropology and related fields, with a brief discussion of where this project fits within this larger body of knowledge. Chapter 3 presents the epidemiology of influenza and the particular characteristics of and previous research into the 1918 pandemic. Chapter 4 describes the history, social structure, and patterns of daily life in Newfoundland communities, including the study community, that informed model design and analyses. Chapter 5 provides an overview of epidemiological modeling with a focus on comparing the theoretical and practical bases and common findings of agent-based and social network models. Chapter 6 describes the specific methods used in this research, including data collection and family reconstitution, the detailed structure and processes of the two models, and strategies for analyzing model output. Chapter 7 presents and discusses results from the systematic comparisons of the models that were performed to understand the range of variation in outcomes within and between models. Chapter 8 focuses on the results for the research questions described above that investigate how the activities of and relationships among different demographic subgroups, such as fishermen and schoolchildren, affect epidemic outcomes for these groups and for the population as a whole. Chapter 9 summarizes major findings from this research and discusses broader implications and future directions. The appendices contain the complete code and input files for both models, a description of how certain measures in the social network model were calculated, and results of statistical analyses further explained in chapter 8.

CHAPTER 2 – THEORETICAL APPROACHES TO THE STUDY OF POPULATION HEALTH

Traditionally, many biomedical and epidemiological studies of human health only consider individual-level risk factors and behaviors. However, more holistic approaches, often adopted by fields such as anthropology and ecology, also take into account, for example, short- and long-term societal or institutional explanations for features of population-level health (e.g. Raphael, 2006). Because studying complex systems or processes, such as changes in health over time or the spread of infectious disease epidemics, is necessarily multifaceted, theoretical approaches are typically employed, which allow researchers to simplify the numerous interacting factors that contribute to various processes, develop testable hypotheses, draw conclusions, and make predictions about the systems of interest.

Theoretical approaches used by medical anthropologists or, more broadly, anthropologists who study health-related issues reflect larger disciplinary concerns of the field. In the United States, anthropology has been conceived as a four-field subject, bringing together cultural anthropology, physical anthropology, archaeology and linguistic anthropology into an ostensibly holistic perspective. At varying times in the discipline's history, however, there have been different levels of contention among members of the subfields regarding whether and how much integration is possible. These disagreements can be seen in the historical development of medical anthropology as well. For example, annual review articles from 40 to 50 years ago indicate that biological and ecological perspectives were commonly recognized among members of the field (e.g. Colson and Selby, 1974; Fabrega, 1971; Scotch, 1963). Some later writings instead merely acknowledge the contributions of physical anthropologists while prioritizing those of cultural anthropologists (e.g. Janes et al., 1986; Young, 1982).

Dating to the early years of medical anthropology as a subdiscipline, as well as in more recent literature, however, researchers have emphasized the bridging role medical anthropology can play between cultural and physical subfields. For example, Alland (1966: 40) wrote that “medical anthropology may serve as a major link between physical and cultural anthropology.” Similarly, Colson and Selby (1974: 257) argued “perhaps…medical anthropology indicates not a conceptually or theoretically bounded subdiscipline, but points to a professional role with its incumbents drawing upon all of anthropology and a number of other disciplines as well.” More recently, publications such as Inhorn and Brown (1990), McElroy and Townsend (2015) and Wiley and Allen (2009) demonstrate the interest in approaches that combine anthropological subfields and related disciplines.

This dissertation exemplifies a biocultural approach to understanding individual and population health, incorporating concepts related to epidemiology and demography as well as concerns regarding social relationships, gendered behavior and community institutions. These aspects will be expanded in more detail in subsequent chapters. Before elaborating on these aspects, however, this chapter presents brief descriptions of several leading theoretical approaches for studying human health which have developed out of both cultural and biological anthropology; potential contributions of this dissertation research are also discussed to demonstrate how these approaches provide foundation to the current study and where it fits within the larger body of anthropological research into the health of human populations.

Social/Cultural Approaches

Typically, medical anthropologists focusing on sociocultural areas of interest have explored topics such as local or culturally-based explanations for the causes, diagnosis and treatment of illnesses, as well as alternative health systems like Ayurvedic medicine, ethical issues, and applications to health care and technologies (see, for example, Inhorn and Brown, 1990; Joralemon, 2010). This approach recognizes biomedicine (i.e. the system most commonly found in “Western” or “cosmopolitan” cultures like the contemporary United States) as one of many paradigms used by humans to make sense of disease and death (Inhorn and Brown, 1990). Other cultural explanations may include, for example, supernatural origins like religion and witchcraft; beliefs about the negative effects resulting from pollution or breaches of conduct; and imbalances of body states, substances or emotions (Erickson, 2008). Studies also have looked at culture-bound illnesses believed to be unique to specific groups, integration or combination of treatments from different medical systems, and how individuals cope with disabilities or diagnoses (e.g. Becker, 1981; Wiley and Allen, 2009).

Janes et al. (1986) stated that early collaborations between the fields of social or cultural anthropology and epidemiology primarily were in psychiatric epidemiology and settings where anthropologists were considered to have useful knowledge, such as research involving traditional societies or developing countries. Eventually, anthropological research spanned a wide range of epidemiological concerns including infectious disease epidemiology (Janes et al., 1986). Around the 1970s, in conjunction with the feminist movement and other factors, interest in “critical medical anthropology” developed. Researchers using this approach frequently critique analyses of health that they claim lack nuanced consideration of issues such as gender, socioeconomic status, and the role of political policies and actions on the distribution and treatment of health conditions. (e.g. Farmer, 1996; Manderson, 1998; Trostle and Sommerfeld, 1996; Vlassoff, 2007). The focus on social, political and economic factors contributed to the development of two major theoretical approaches: social determinants of health and syndemics.

Social determinants of health

Primarily a European but not strictly an anthropological approach, research into the social determinants of health emphasizes systematic structural or institutional disparities in health measures or outcomes, both within and among different regions (Marmot, 2005; Raphael, 2006). Although individual behavioral choices might be recognized or evaluated, they are considered alongside or within the underlying physical and social environment or context in which individuals make those choices (e.g. Denton and Walters, 1999). Various works have identified different determinants, which typically include education, employment and working conditions, food security, housing, income, access to health care services, and social support or exclusion (e.g. Bambra et al., 2010; Marmot, 2005; Raphael, 2006).

Results have shown that the relationship between social determinants and health is not a simple correspondence. Importantly, there is not an absolute or mutually exclusive relationship between poor health and low status; rather there is a gradient in the level of health based on relative position on a socioeconomic scale (Blane, 1995; Marmot, 2003). Further, the effects or importance of determinants vary for subgroups of populations, such as different genders or immigrant groups (Braveman and Tarimo, 2002; Denton and Walters, 1999; Dunn and Dyck, 2000).

Much of the research done within this framework is agenda-driven or policy-related (e.g. Bambra et al., 2010; Marmot et al., 2008). Indeed, publications such as the Black Report, produced by a commission to address persistent disparities decades after the implementation of the United Kingdom's National Health Service (Black et al., 1980; Marmot, 2003), and the Whitehall Study of British Civil Servants (Reid et al., 1974) were among the precursors to the establishment of the Commission on Social Determinants of Health by the World Health Organization. This Commission, as part of its goals, aimed to translate research findings into recommendations for policies and actions (Marmot, 2003; Marmot, 2005). The final report of the Commission identified three principles related to improving quality of life, addressing inequalities and expanding awareness of determinants (Marmot et al., 2008; Commission on Social Determinants of Health, 2008). While this focus on policy agendas serves an important function, it might also raise concerns about the objectivity or purpose of analyses and results of research conducted under this framework.

Although social determinants of health are not explicitly considered in the current research project, the study community provides potential comparisons or considerations at multiple levels of this framework. As discussed in future chapters, most communities in the region at the time were poor, with limited access to health care services or higher education. While there were some differences in status or wealth among residents within communities, these differences were often minor. Thus, analyses allow consideration of other social determinants that may have contributed to epidemic outcomes within and between communities; for example, while there was minimal variation in the socioeconomic gradient, food insecurity and dangerous working conditions likely played a large role in health outcomes because of the community's reliance on fishing activities. In general, this research demonstrates that historical studies of small-scale or local communities can provide further insight into many of the social determinants of health affecting contemporary regions and policies.

Syndemics

Influenced by concepts of the social determinants framework, syndemics strategies also study the complex interaction of society and health. However, a more explicit consideration of pathogens and disease shifts this framework more towards a biocultural approach. Frequently, research into health conditions may consider certain diseases or ailments in isolation. Biomedical concepts or categories of disease treat such conditions as isolated, bounded entities with specific, known causes. A syndemic approach, as defined by Singer and Clair (2003), recognizes the interaction of multiple illnesses or pathogens within a social context, particularly emphasizing factors such as poverty, stigma or negative environmental conditions. Specifically, the illnesses or conditions are assumed to not only co-circulate, but also have a direct or indirect additive or enhancing effect so that symptoms or consequences are novel or worse than would have been caused by any of the conditions in isolation (Singer and Clair, 2003).

Numerous publications have identified syndemics associated with HIV/AIDS, exploring the relationship of this virus/disease with, for example, mental health burdens, drug use, and sexual or partner violence (e.g. Halkitis et al., 2013; Illangasekare et al., 2013; Meyer et al., 2011; Mustanski et al., 2007). Other research, including publications from a recent special issue of *Annals of Anthropological Practice*, has identified syndemic interactions between poverty and dental care (Kline 2013), tuberculosis and helminths (Littleton et al., 2013), and the effects of war on societal organization and infrastructure and the subsequent impacts on health (Ostrach and Singer, 2013).

The 1918 influenza pandemic, which is the focus of this current research, has also been identified as a syndemic (e.g. Herring and Sattenspiel, 2007; Sattenspiel and Mamelund, 2013). As discussed in more detail in later chapters, observed regional and local variation in pandemic outcomes can be explained by disrupted infrastructure or societal factors such as access to health care or other resources, the impact of World War I, and preventive measures enacted in attempts to mitigate the spread of disease. Further, much research has demonstrated the harmful effects of pre-existing or co-circulating pathogens, including tuberculosis and pneumonia, on morbidity and mortality rates during the pandemic. In the case of tuberculosis, for example, which was a widespread problem in the early 20th century, lung tissue damaged by the disease provided additional surface for the influenza virus to take hold (e.g. Shanks and

Brundage, 2012). Research into the 1918 pandemic has examined both global and local experiences to richly describe the components necessary for a syndemic; this project contributes to this body of research by looking at the experiences of a specific community. Analyses at the community level allow for detailed consideration of the interacting biological and social factors that may have contributed to the syndemic, including individual heterogeneity in immunity and community responses to illness.

Physical/Biological Approaches

Compared to the above approaches, research conducted by biological anthropologists, archaeologists and, often, non-anthropologists in related fields more commonly uses biomedical or biocultural understandings of disease and often focuses on questions related to ecological or evolutionary factors contributing to the distribution of disease (Inhorn and Brown, 1990). In more general epidemiological research, this perspective became particularly dominant in the late 19th and early 20th century as the "germ" theory of disease causation replaced beliefs that disease was caused by, for example, miasma or decaying matter in the air. It was during this time period that August Hirsch, a medical geographer, may have been the first to use the term medical anthropology (Trostle, 1986).

More recent anthropological studies have used bioarchaeological and other evidence to address the origins and spread of diseases, such as syphilis, in human history (e.g. Baker and Armelagos, 1988; Crosby, 1969; Hudson, 1965; Livingstone, 1991; Powell and Cook, 2005). Other studies have investigated the co-evolution of humans and pathogens, the role of human behavior in the spread of zoonoses from animals to humans, and the distribution of traits such as ABO blood types related to the prevalence of diseases like cholera and malaria (e.g. Cserti and Dzik, 2007; Harris et al., 2005; Sattenspiel, 2015; Van Blerkom, 2003; Wolfe et al., 2005).

Research using an ecological or evolutionary approach, however, typically still incorporates social and cultural variables such as insights from observed human behavior. For example, studies have explored the social context influencing the relationship between water use patterns and schistosomiasis infections (e.g. Dalton and Pole, 1978; Farooq and Mallah, 1966; Yi-Xin and Manderson, 2005). Dunn and Janes (1986:22) argued that research into the relationship between the sickle cell trait, malaria, forest clearing and crop cultivation and other factors (e.g. Allison, 1954; Livingstone, 1958; Wiesenfeld, 1967) synthesized biocultural and evolutionary concepts in a way that was of "greater fundamental importance in anthropology than in any other disciplines [the studies] touched." Like the foundational studies cited above, more recent research in anthropology and related fields continues to combine ideas from evolutionary theory, ecology, the social and cultural environment, and biomedical concepts of pathogens and disease, including studies exploring maternal stress and offspring health (e.g. Thayer and Kuzawa, 2014), biological and cultural causes of obesity (e.g. Bellisari, 2013), and factors influencing long-term trends and transitions in health and demography (e.g. Zuckerman, 2014).

Transition theories

Transition theories are models for understanding changes in population characteristics over time. Two major, interrelated transitions dealing with human populations and health trends are the demographic and epidemiological transitions. Broadly speaking, demographic transition theory considers patterns in mortality and fertility rates and related population growth, while epidemiological transition theory considers the relative proportions of infectious, chronic, or other diseases as major causes of death.

The demographic transition. Demographic transition theory, including early formulations by Thompson (1929) and Notestein (1945), proposes a shift from a period of high mortality and fertility rates to a stage where both are low (Kirk, 1996). Fertility declines typically lag behind mortality changes, and during this lag, population size grows rapidly (Gage, 2005; Kirk, 1996; Teitelbaum, 1975). However, this model of population growth was originally developed to explain trends observed around the time of the Industrial Revolution in Europe and North America. Later extensions and critiques have focused on other regions and time periods. For example, attempts to apply the European model to developing countries, especially post World War II, have revealed vastly different causes and consequences that must be considered and call into question the relevance of the theory for explaining more general phenomena (e.g. Teitelbaum, 1975; Watkins, 1987). Teitelbaum (1975) argued that pre-transition fertility rates are generally higher in developing countries than in pre-transition Europe, mortality changes are more dramatic and due to imported technologies rather than internal social and economic development as in Europe, and that population growth therefore is unprecedented in developing countries and transitions can be expected to be completed more rapidly. Similarly, less developed communities even within developed regions or countries (such as the study community used in this research; see, for example, Freeman, 1971) may have different experiences in timing, causes or impacts of demographic change relative to the surrounding areas. Additionally, researchers have drawn upon the transition framework to propose a Neolithic Demographic Transition (NDT). This model suggests that increased fertility corresponding with the origins of agriculture and more sedentary populations led to population growth, which was eventually mitigated by increased mortality and other factors (e.g. Bellwood and Oxenham, 2008; Bocquet-Appel, 2002).

The original European and North American model, however, considers preindustrial populations that, prior to the transition, experienced no or slow population growth. Unlike in the Neolithic demographic transition theory, mortality changes occurred before fertility changes. Periods of “normal” levels of mortality were punctuated by episodes of “crisis” mortality from epidemics and similar catastrophic causes. These crises began to decline both in frequency and magnitude prior to the second stage but still continued into the 20th century, particularly with influenza. In fact, the 1918 influenza pandemic perhaps marked the last of the “crisis” mortality episodes (Gage, 2005).

The second stage or phase of the European and North American demographic transition involves continued mortality declines, recognized in the literature as beginning in some European countries, including Sweden, England and Wales, in the mid-19th century, and ending around World War II. The third stage is characterized by declines in fertility rates driven by a variety of social, cultural and biological factors, while stage four populations have low mortality and fertility rates, reflecting completed demographic transitions. These stages are not discrete, however, with trends continuing into the subsequent stages, albeit at possibly smaller rates (Gage, 2005; Teitelbaum, 1975).

The epidemiological transition. Epidemiological transition theory recognizes the role of natural, social, demographic, behavioral and other environmental factors on the prevalence and likelihood of transmission of different pathogens over time and across different geographical areas. This framework was developed to offer explanations for the population growth observed in the European demographic transition, with the proposed second epidemiological transition particularly focused on identifying and understanding causes for the large declines in mortality. The theory was first proposed by Omran (1971), who classified the epidemiological histories of different regions into broad ages or categories: the Age of Pestilence and Famine, the Age of Receding Pandemics, and the Age of Degenerative and Man-Made Diseases. Further development of these ideas, by Omran and other researchers (e.g. Barrett et al., 1998; Harper and Armelagos, 2010), expanded the framework to include additional time periods or stages and heterogeneity in the experiences of different locations.

In this expanded framework, the earliest phase or stage frequently discussed is referred to as the Paleolithic baseline, encompassing much of human history, when individuals lived as nomadic foragers. Small group sizes and wide dispersal prevented the maintenance of most communicable diseases, although some pathogens which predated the hominin lineage split, or which transferred to humans from irregular or chance encounters with other hosts, may have been present (Barrett et al., 1998; Cockburn, 1971). Additionally, infections may have occurred from the consumption of raw food or through exposure to diseases carried by ticks, mosquitos, or other vectors, while food shortages or famines may have contributed to weakening of the immune system (Burnet and White, 1972; Cockburn, 1971).

The first epidemiological transition thus refers to the shift from this stage to one coinciding with the origins of agriculture. This general time period included a number of related changes to social structure and patterns of behavior. For example, population groups became larger in size, more reliant on staple crops, more sedentary, and more stratified. These changes resulted in different contact rates among individuals allowing for the spread and maintenance of communicable infectious diseases, as well as illnesses related to waste and sanitation issues and the domestication of animals (Barrett et al., 1998; Burnet and White, 1972; Cockburn, 1971; Harper and Armelagos, 2010).

As mentioned above, the second epidemiological transition roughly corresponds, at least in Western countries, with the Industrial Revolution and the mortality declines observed by demographic transition theory. Around this time, mortality from infectious diseases declined while the impact of chronic diseases increased. Contributing factors to the decline in infectious disease likely included improvements in living conditions and sanitation, particularly in larger cities. While advances in medical knowledge such as the development of vaccines or antimicrobials may have contributed somewhat, especially in areas where the transition happened later, these advances were not the sole or driving influence (Barrett et al., 1998; Harper and Armelagos, 2010; McKeown, 1976). However, Gage (2005) cautions that a shift in proportions of the causes of death does not necessarily indicate a change in the age-specific risks of dying from different causes. Because proportions must add up to 100, a decline in one cause requires an increase in another category.

Prompted by recent trends and the recognition that infectious diseases never fully disappeared in many parts of the world, researchers have proposed a third epidemiological transition currently in progress, wherein infectious diseases are becoming more prevalent and/or more severe. Emerging and re-emerging diseases, such as Ebola, SARS, multidrug-resistant tuberculosis and others, are likely influenced by globalization, shifts in public health priorities, and other factors such as environmental changes like global warming (Barrett et al., 1998).

This research project considers a population that, at the time of the 1918 pandemic, had not yet undergone the second epidemiological transition despite its relative proximity to major cities and the more developed countries of Canada and the United States. The timeframe immediately preceding the transition is an important period that is often overlooked as studies typically focus on the causes and consequences of the transition itself. Further, analyses have demonstrated the importance of local-level studies which can help tease out more nuanced explanations for contributing factors and timing of the transition in different parts of the world, especially rural or isolated communities such as the study community used for this research (Sattenspiel and Stoops, 2010; Sattenspiel and Lander, 2014).

Although the above discussion is not an exhaustive exploration of different theoretical approaches, the examples indicate that frameworks for studying population health are not mutually exclusive and the overlap of concerns and strategies provides an avenue for integrating biological and cultural subfields. This project similarly combines insights from both subfields, as well as other disciplines such as history, epidemiology and computer simulation, to address specific research questions regarding the spread of infectious disease in a small study community. However, not all of the frameworks described above can or should be used in a single study. While future developments of this project may allow for more explicit examination of, for example, social determinants of health or syndemic interactions, the current study fits better within a broad biocultural approach influenced by ecological applications (considering both the social and physical environment) and transition theory.

Research questions consider the role in disease transmission of gender- and age-related behavior informed by the regional economy centered on the marine subsistence base of the study community. These behaviors and roles arising from the local context combine ethnographic and ecological perspectives to understand how a pathogen, conceived in the biomedical sense as a disease-causing organism, circulates among a population. Further, the historical nature of this study contributes to the understanding of health characteristics and experiences of a traditional community, relatively undeveloped for its North American location, just prior to the second epidemiological transition. Therefore, the questions addressed in this study demonstrate the applicability of multiple frameworks for a deeper understanding of human health and demography over time.

CHAPTER 3 – INFLUENZA AND THE 1918 PANDEMIC

Beginning in 1918, the worldwide spread of the “Spanish flu” killed an estimated 675,000 Americans and as many as 50-100 million people worldwide (Johnson and Mueller, 2002; Tumpey et al., 2005). This pandemic has been of great interest to both academics and the general public, due in part to recent threats such as SARS and the 2009 H1N1 pandemic (e.g. Crosby, 2003; Phillips and Killingray, 2003; Sattenspiel, 2009; Simonsen et al., 2011). Seen as a worst case scenario, the devastation caused by the pandemic provides valuable insights into the factors that contribute to local and global transmission and outcomes of infectious diseases. This chapter first describes the biology of the influenza virus, then provides an overview of the epidemiology of flu among humans in both seasonal epidemics and more severe but rarer pandemics, and concludes with a discussion of the characteristics unique to the 1918 virus and pandemic, as well as a sample of findings from studies on this major historical event.

The Influenza Virus

The virus that causes influenza, identified in 1933, is a member of the orthomyxoviridae family and consists of eight discrete RNA segments (Chowell et al., 2006; Taubenberger, 2003). Reassortment of this genetic material results in different strains, which are grouped into three types: A, B and C (Ahmed et al., 2007). Individual strains are identified by the properties of antigens on the surface of the virus. Sixteen hemagglutinin and nine neuraminidase antigens are known to exist in influenza viruses that infect animals (Horimoto and Kawaoka, 2005). Antigenic properties change in two ways, drift and shift. Antigenic drift results from the accumulation of small mutations, such as substitutions, deletions and insertions, that lead to minor changes to the surface proteins, particularly hemagglutinin. Shift is typically caused by reassortment of genetic material from different animal and human strains, or is associated with the jump of the virus directly from an avian or animal reservoir host without reassortment (Cox and Subbarao, 2000; Sattenspiel, 2009). Conventionally, drift is considered to be responsible for creating the different strains that allow for relatively mild, annual outbreaks of influenza, while shift is frequently credited with larger and more severe pandemics as the major changes to surface proteins can lead to a new form of the virus to which most individuals are susceptible (Cox and Subbarao, 2000; Morens et al., 2009; Sattenspiel, 2009). However, this distinction has been challenged, since viruses can be modified through other genetic mechanisms as well, including reassortment within subtypes. For example, the development of the virus that caused the 2009 H1N1 pandemic, which is descended from the 1918 pathogen, included genetic mixing within human viruses and between avian- and swine-viruses, and selective pressure from herd immunity in different populations over time (Morens et al., 2009).

The natural reservoir of the influenza virus are birds, particularly those adapted to aquatic lifestyles such as members of the *Anseriformes* and, to a lesser extent, the *Charadriformes* and *Laridae* families, such as ducks, geese, swans, waders and gulls (Wahlgren, 2011). Influenza also can affect many other species, including horses, whales, seals and pigs (Fleming, 2005). Only a few subtypes of A and B viruses are important for causing diseases in humans (Nguyen-Van-Tam and Hampson, 2003;

Wahlgren, 2011). The key feature of the transition from an animal or avian virus to one which can easily infect humans involves modifications to particular receptors. Receptor binding is the initial event in infection and is mediated by the hemagglutinin protein (Gamblin et al., 2004).

Historically, pandemics in human populations have been caused by avian-derived viruses. However, the receptor structures and anatomical locations necessary for flu viruses to attach and replicate differ between birds and humans (Gamblin et al., 2004; Holmes, 2004). Therefore, an intermediate step where swine, which can be simultaneously infected with human and avian strains and thus can serve as mixing vessels to create novel strains, may be required. However, recent incidents demonstrate that influenza viruses can cause outbreaks in humans without an intermediate host, though human to human transmission of these strains remains more difficult (Cox and Subbarao, 2000; Horimoto and Kawaoka, 2005).

Influenza in Humans

With strains that can be spread among humans, transmission occurs through inhalation of the virus or through direct contact with respiratory tract secretions of infected individuals (Fleming, 2005; Heymann, 2015). Once infected, a new case might begin spreading the virus within one day. Symptoms often appear within one to four days and include high fever, myalgia, severe malaise, non-productive cough and a sore throat (Chowell et al., 2006; Heymann, 2015). A person remains infectious for three to six days on average, or longer in children or immunocompromised individuals, with full recovery occurring about a week after infection (Fleming, 2005; Heymann, 2015).

Complications include otitis media (middle ear infections), primary influenza pneumonia, secondary bacterial pneumonia and bronchitis, and, rarely, encephalitis, as well as the worsening of preexisting conditions like cardiac failure and diabetes (Fleming, 2005). Upon recovery, infected individuals are immune to the particular strain and closely related ones (Chowell et al., 2006; Heymann, 2015).

At local and regional levels, household and community features play significant roles in the spread of influenza. As much as 30% of flu transmission may occur within the home (Ferguson et al., 2006). At least in the case of the 1918 pandemic, analyses suggest that proximity and frequent contact, rather than genetic susceptibility, is likely responsible for clusters of deaths within families (Gottfredsson et al., 2008). Household size and composition can strongly influence epidemic outcomes. For example, larger households have a higher chance of a member bringing disease into the household as well as increased rates of transmission within the house due to more contacts (House and Keeling, 2009). According to House and Keeling (2009), larger households also tend to have more dependent children, indirectly implicating the importance of this demographic subgroup in disease spread.

In a comparison of pandemic and seasonal flu measures, Cowling et al. (2010) found that the proportion of household members who subsequently developed influenza was higher, although not significantly, for index cases aged 15 years old or younger than when older individuals were the first cases in a household. Schoolchildren also play an important role in the spread of disease within the community. For example, outbreaks of the 2009 H1N1 pandemic have been associated with the timing of school opening dates in the United States (Chao et al., 2010) and holiday-related closures in India (Ali et al., 2013). Previous studies of earlier influenza epidemics and other diseases suggest that, overall, transmission of disease within the community or public domain is more frequent and can give rise to larger epidemics than household transmission (Cairncross et al., 1996; Elveback et al., 1976; Nishiura and Chowell, 2007)

On average, five to fifteen percent of the global population becomes infected during annual seasonal epidemics, which results in about 250,000 to 500,000 deaths (Noce et al., 2011; Russell et al., 2008). In the United States alone, annual deaths total 35,000 and this number has increased over the last 25 years (Sattenspiel, 2009). Based on 2005 U.S. population data, Molinari et al. (2007) estimated that annual epidemics result in an average of about 611,000 life-years lost, 3.1 million hospitalized days and 31.4 million outpatient visits. Considering direct medical costs, lost earnings, and other factors, the total economic burden of annual epidemics adds up to $87.1 billion dollars, with the bulk of the impact due to lost productivity and lost lives (Molinari et al., 2007).

Pandemic Influenza

Pandemic influenza often has much larger and more severe consequences and varies from seasonal epidemics in a number of ways, including timing and age distribution of cases. Seasonal flu peaks occur in winter in temperate regions (November to March in the northern hemisphere and April to September in the southern hemisphere) and can occur throughout the year in tropical regions (Cox and Subbarao, 2000; Nguyen-Van-Tam and Hampson, 2003). Local seasonal epidemics last about five to ten weeks with peaks around two to three weeks (Cox and Subbarao, 2000; Glezen and Couch, 1978). Pandemic flu, which can occur in multiple waves of infection, is less constrained, occurring at any time of the year and throughout the world more or less simultaneously (Fleming, 2005; Nguyen-Van-Tam and Hampson, 2003). Further, seasonal influenza tends to preferentially lead to complications and deaths among the young and elderly, particularly those with underlying conditions. Changes in the age distribution of cases are frequently seen during pandemics, with increases in morbidity and mortality among young adults (Luk et al, 2001; Nguyen-Van-Tam and Hampson, 2003; Simonsen et al., 2011). For example, the mean age of death from confirmed cases in 2009 during the H1N1 pandemic was 37 years, much lower than the mean age of 76 years observed during recent seasonal epidemics (Simonsen et al., 2011).

Such comparisons of the 2009 H1N1 pandemic showed some similarities and some differences to historical pandemics in outcomes and patterns, illustrating the importance of interdisciplinary research into the characteristics of these events (Simonsen et al., 2011). Previous research has considered several major influenza pandemics in the 20th century, including: the 1957 Asian influenza A (H2N2) which resulted in approximately 115,700 excess deaths (i.e. the number of deaths above what would be expected from normal seasonal flu patterns), the Hong Kong influenza A (H3N2) with an excess mortality of 98,100 deaths between 1968 and 1971, and the "Spanish flu" (type A, H1N1) of 1918 (Glezen, 1996). This early, particularly severe pandemic is the most notable and the most frequently studied among researchers.

The 1918 Pandemic

The cause of influenza was unknown at the time of the 1918 pandemic, though suspected pathogens included the bacterium *Bacillus* (now *Hemophilus*) *influenzae* (Barry, 2005). Research during and following the pandemic and World War I investigated a variety of potential causes and resulted in the virus being isolated in the early 1930s by researchers including Wilson Smith, C. H. Andrews, and P. P. Laidlaw (Crosby, 2003). Beginning in the mid-1990s, Jeffery Taubenberger and other researchers were able to isolate and identify the strain of virus responsible for the 1918 pandemic from samples obtained from U.S. soldiers who died during the pandemic and stored at the Armed Forces Institute of Pathology and from an Inuit woman who had been buried in permafrost in Alaska (Taubenberger, 2003; Taubenberger et al., 2001). Subsequent analyses by the Taubenberger laboratory as well as other researchers have highlighted several important features of the virus strain. For example, the polymerase genes are structurally similar to avian viruses and likely resulted from the direct transfer of these genes from an avian virus into a human virus (Kaiser, 2005; Sharp, 2005). These polymerase genes allow the virus to grow very efficiently in human bronchial cells, and indeed the virus can possibly grow in any cell type, not just lungs. Further, the virus kills chicken embryos unlike other human viruses, and it kills mice more quickly than any other known human flu virus (Kaiser, 2005; Tumpey et al., 2005). Overall, the most distinctive features are the receptor binding properties of the hemagglutinin antigen; its distinctly avian structure may explain the virulence of the virus, but it still recognizes human cells (Gamblin et al., 2004; Holmes, 2004). This novel virus, particularly the virulent hemagglutinin combined with the ability to easily infect humans, and other important factors including global movement of troops during World War I created perfect conditions for a pandemic.

The 1918 pandemic gained the nickname “Spanish flu” because Spain’s neutrality during World War I allowed news coverage of the illness, whereas news outlets in other countries were censored (Phillips and Killingray, 2003). However, the flu most likely first appeared in Kansas, although other origins such as China have been proposed (Barry, 2005; Crosby, 2003; Cox and Subbarao, 2000; Humphries, 2013). Outbreaks of a flu-like illness in England and France in 1916 and 1917 may have been early cases caused by the same strain (Oxford, 2001). The first generally recognized wave of the pandemic occurred in the spring and summer of 1918. The first wave was relatively mild with much sickness but very low mortality. The majority of deaths occurred during the second wave, which hit in autumn 1918. Another mild wave took place in early 1919, and some areas also experienced what may have been a small echo wave in 1920 (Johnson and Mueller, 2002; Sattenspiel, 2011). The occurrence and timing of these waves were not universal however; for example, Alaska only experienced two waves corresponding to the second and third global waves (Mamelund et al., 2013)

Estimated values of R_0, or the average number of secondary infections transmitted by an infectious individual in an otherwise susceptible population, for the pandemic are commonly around 1.3-2.5 (though sometimes higher, particularly for the second wave), indicating the strain was not unusually transmissible compared to seasonal epidemics or other infectious diseases (Chowell et al., 2006; Chowell et al., 2008; Mills et al., 2004; Sattenspiel, 2009; Sattenspiel 2011). Further, case fatality rates, estimated at 2.5-3% for most populations, and overall mortality rates, which averaged 2.5-5 per 1000 globally, while higher than in typical seasonal epidemics , demonstrate that the majority of affected people still survived the pandemic (Johnson and Mueller, 2002; Shanks and Brundage, 2012; Taubenberger and Morens, 2006). However, in pandemic situations, extremely high morbidity rates, even with low mortality rates, result in an overall high number of deaths (Phillips and Killingray, 2003). The 1918 flu was no exception, with an estimated 50% of the world population becoming infected compared to typical seasonal epidemics where 5-25% become infected (Mills et al., 2004; Nguyen-Van-Tam and Hampson, 2003; Russell et al., 2008).

The exceptional mortality, particularly during the second wave, was just one unique characteristic of this pandemic. Another was the age distribution of deaths. As mentioned above, most annual flu epidemics result in a U-shaped mortality curve reflecting high death rates among the very young and the elderly. In contrast, the 1918 pandemic exhibited a W-shaped mortality curve (Figure 3.1). Young adults were affected more severely than typically expected, although these age groups still were less likely to die than those at the extreme ends of the age distribution (Olson et al., 2005; Sattenspiel, 2009). Potential explanations for this age-specific mortality have often focused on immune system effects from prior exposure to different influenza strains. For example, older age groups or urban residents may have had more protection from pre-existing immunity than younger adults or rural populations (e.g. Mathews et al., 2010, Saglanmak et al., 2011). Alternatively, researchers have argued that early childhood exposure to a dissimilar strain may have predisposed immune systems of young adults to respond aggressively and pathologically to the 1918 virus. A peak of mortality around the age of 28 observed in some areas corresponds to the cohort born around the time of the 1890 Russian pandemic caused by an H3 virus, which has been presented as support for this hypothesis (Gagnon et al., 2013; Gagnon et al., 2015; Hallman and Gagnon, 2014; Wilson et al., 2014).

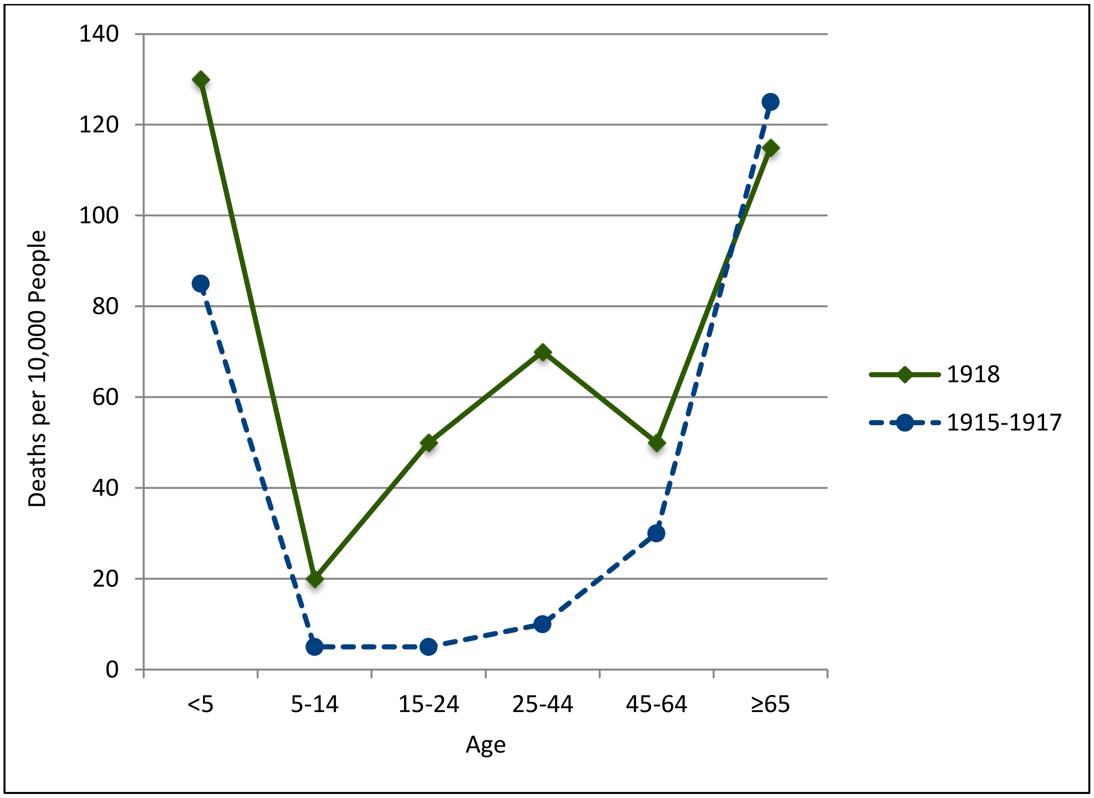


Figure 3.1. Age-specific mortality curves comparing 1918 and earlier years, demonstrating unusually high mortality rates for young adults that produced the characteristic W-shaped curve associated with the pandemic. Data from Olson et al., 2005, Figure 2a.

Deaths from influenza itself were often attributed to an excessively strong immune response and could occur very suddenly (Barry, 2005; Crosby, 2003; Kobasa et al., 2007). However, more prolonged deaths were often caused by complications from secondary infections, particularly bacterial pneumonia, or complicated by pre-existing conditions and co-circulating pathogens such as tuberculosis (Brundage and Shanks, 2008; Noymer and Garenne, 2000; Shanks and Brundage, 2012). Symptoms of the 1918 strain of influenza often were similar to but more severe than typical influenza; such symptoms included fever, headache, myalgia, and nausea. More unusual symptoms characteristic to the pandemic included epistaxis (bleeding from the nose), cyanosis (purple coloration of skin due to low oxygen), and lung pathologies such as massive pulmonary edema or hemorrhage (Brundage and Shanks, 2008; Cox and Subbarao, 2000; Nguyen-Van-Tam and Hampson, 2003; Phillips and Killingray, 2003).

Different regions mounted various responses to the threat of the pandemic, which varied in effectiveness but often failed to stop the spread of the disease. For example, Chowell et al. (2006) described efforts in Geneva that included school and church closures, prohibition of public events, mandatory spraying of disinfectants on streets and authorizations of burials within 48 hours of death. However, there is no evidence that these measures were effective due to the general disruption of the various private and public sectors. Crosby (2003:100-101) mentioned efforts involving highly publicized vaccines with “no immunologic value,” and the compulsory wearing of masks, which may have had some benefits but overall was ineffective. Mamelund et al. (2013) suggested quarantine efforts may have worked in some Alaskan communities due to early implementation and enforcement of these measures, while quarantines were largely unheeded and thus unsuccessful in parts of Labrador. In an analysis of interventions imposed by 43 U.S. cities, Markel et al. (2007) found that the most common measure was a combination of school closures and cancellation of public gatherings. This combination was significantly associated with a reduction in weekly excess death rates, and earlier implementation was associated with outcomes such as longer delays before reaching peak mortality and lower total mortality (Markel et al., 2007).

Despite such attempts to mitigate the impact, mortality from the 1918 flu resulted in notable demographic consequences during the pandemic itself and in the years immediately after. Some of the observed outcomes during the pandemic may be due to World War I. For example, Rewegan et al. (2015) found increased mortality from pneumonia and influenza among Canadian soldiers coinciding with the first wave of the pandemic. Mortality rates were especially high in the Maritime provinces, probably because numerous Canadian and American troops departed for Europe from these eastern ports and sick soldiers were often left behind and thus counted among the deaths for that region (Rewegan et al., 2015). Further, Humphries (2005) argued that the disease was introduced into Canada by American soldiers and then spread westward from various parts of the country including New Brunswick and Quebec with the mobilization of the Siberian Expeditionary Force as it prepared to depart from Vancouver.

World War I factors may also be responsible in some cases for observed differences between the sexes. For example, in areas of France farther away from the front, mortality rates among males aged 15-44 years were higher than for females. This difference could be due to the fact that the men in this age bracket remaining in these areas were likely deemed medically unfit rather than conscripted by the military and so would have been more vulnerable to infection or complications. Conversely, in areas closer to the front or in neutral countries like Spain, the differences between sexes were smaller or the patterns were reversed (Zylberman, 2003). In the United States, the segment of the population most vulnerable and most likely to die from the disease was pregnant women. Results from 13 studies of hospitalized women indicated that mortality rates were 23-71% and among the women who survived, 26% of them lost the child (Barry, 2005).

In fact, birth rates declined in several other countries as well, including Denmark, Sweden and Norway, by a mean of 2.2 births per 1000 or a 5-15% drop. These declines could not be attributed only to mortality of pregnant women. Instead, the timing of the trough of the depression at about 6.1-6.8 months after the peak of the second epidemic wave suggests the declines in birth rates were largely due to excess first trimester miscarriages. Further supporting this hypothesis are results from a 1919 report on 1350 pregnant women with influenza that showed 26% miscarried, with an even higher proportion of 52% among women who experienced complications from pneumonia. However, an increase in births within one year compensated for the observed declines and indicated fertility was not permanently impacted by the pandemic (Bloom-Feshbach et al., 2011).

Similarly, the age distribution of deaths from influenza reverted to seasonal patterns and, although life expectancy in the United States dropped by 11.8 years for both sexes from 1917-1918, these measures quickly bounced back as well, implying no lasting effect from the pandemic (Noymer and Garenne, 2000; Simonsen et al., 2011). However, the impact on differential life expectancy between the sexes was slightly more prolonged. Comparisons of the differences in life expectancy in the U.S. before and after 1918 showed that females did not regain the same degree of advantage until the mid-1930s (Noymer and Garenne, 2000). Noymer and Garenne (2000) suggested a connection with tuberculosis: men were more likely to be infected with tuberculosis at the time of the pandemic, which may have made them more vulnerable to the flu itself and to complications from the often fatal secondary bacterial pneumonia. Higher rates of mortality among these individuals removed them from the pool of potential tuberculosis deaths later in the century, resulting in life expectancies closer to females (Noymer and Garenne, 2000). However, this pattern was not universal; for example, Sawchuk (2009) found that in Gibraltar, there was little subsequent impact on male mortality immediately following the pandemic and tuberculosis rates returned to their previous levels for both sexes.

Occasionally contradictory observations such as these demonstrate the important insights that can be gained from local and regional data. For example, mortality rates in communities in Alaska and Labrador varied from less than 1% up to 90% (Mamelund et al., 2013); it is likely that such extreme disparities occurred elsewhere as well. This observed variation in epidemic experiences and outcomes cannot be fully explained by virus characteristics or global transmission patterns; contributing factors must include household and community attributes such as demographic composition, nutrition, access to health care, the physical environment, behaviors and activities, responses to crisis events, and potential prior immunity, as well as a variety of other factors. For example, Murray et al. (2006) analyzed mortality records from 27 countries and 24 U.S. states and found that nearly half of the 30-fold variation in mortality can be explained by per capita income, with a nine to ten percent decrease in mortality for every ten percent increase in income. Chowell et al. (2008) found a 30-40% higher mortality in English and Welsh cities and towns than in more rural areas, with population size and urbanization being the predictors of death in the second and third waves. While there was little variation in death rates in cities and towns of different sizes, smaller rural communities had disproportionately larger per capita mortality than larger rural communities (Chowell et al., 2008). A model incorporating 1918 survey data from Maryland indicated that up to 22% of the Baltimore population might have had prior immunity from exposure during a largely unreported epidemic in the spring of 1918; lower levels of prior immunity could have then explained the substantially larger attack rates in Frederick, Maryland during the pandemic (Fraser et al., 2011). Herring and Sattenspiel (2003) found that, in fur trapping communities in Manitoba, where families tended to be dispersed and isolated during the winter, almost a quarter of all deaths were clustered within several nuclear families while about 70% of families reported no deaths. Further, Mamelund et al. (2013) proposed a number of biological and cultural, political and socioeconomic, and environmental and geographic factors that could have contributed to the signification variation seen within and among villages in Alaska and Labrador, where some communities suffered up to 90% mortality while others escaped entirely. Local and regional studies such as these demonstrate the important and idiosyncratic factors that contribute to, and in turn are influenced by, larger epidemiological patterns and outcomes.

This project contributes to this body of research by testing hypotheses related to local factors – including household composition and kin relationships; typical daily activities of men, women and children; and the role of important social institutions such as churches and schools – in the spread of influenza in a small Newfoundland community. In the next chapter, the ethnographic and historical features of the province of Newfoundland and Labrador and of the study community itself are described, followed by an overview of the 1918 pandemic experience in this region.

CHAPTER 4 – HISTORICAL AND ETHNOGRAPHIC BACKGROUND OF NEWFOUNDLAND

This research focuses on the study community of Newell's Island, Newfoundland and Labrador, in the early 20th century. Queen and Habenstein (1974) argued that, at least prior to Confederation with Canada in 1949, most Newfoundland outports (small coastal settlements outside of larger cities like the capital of St. John's) fit into a classic pattern of organization at both the household and community levels. Thus, findings from this research can be extrapolated for insights into disease transmission in small, traditional, kin-based communities across Newfoundland and potentially elsewhere. This chapter describes the broad features of life and the typical activities and relationships of men, women and children discussed in multiple ethnographic and historical sources about Newfoundland, before providing more specific details on the study community. The chapter concludes with a discussion of the health conditions and the 1918 influenza pandemic experience on the island of Newfoundland and in the study community.

History and Settlement of Newfoundland

The island of Newfoundland (Figure 4.1) is located off the east coast of Canada. Together with the continental region of Labrador, which is located on the Labrador Peninsula of mainland Canada to the northeast of Quebec, Newfoundland became the country's tenth province in 1949. The history of exploitation and settlement of this region is deeply rooted in its ecological context emphasizing marine resources and a subarctic environment that largely prevents other types of activities such as farming. Geologically speaking, several major features produce these ecological conditions. For example, the regions of deeper water corridors around the Labrador Sea form part of the migratory routes for the many species of fish that have been historically harvested in the region. Further, the Grand Banks, a continental shelf off the southeast coast of the island, serves as a barrier to the warm Gulf Stream as it flows north and to the cold, south-flowing Labrador Current, which also mixes with other currents in different regions surrounding the island. The meeting of these two major currents produces a blend of temperatures and nutrients that support food chains for a variety of marine animals. Additionally, the withdrawal of glaciers about 10,000 years ago created rough, sparse terrain on the island itself, largely limiting agriculture capability (Cadigan, 2009).

Archaeological evidence suggests Maritime Archaic aboriginal populations first colonized the island around 5000 years ago, followed by several waves of different groups (Rankin, 2008). The most recent aboriginal group in Newfoundland was the Beothuk, with evidence of this culture appearing around the 15th century. Like previous groups, the Beothuk relied heavily on marine resources, using canoes to travel to outer islands and hunt seals and small whales. In winter months, these groups typically moved inland and turned to resources such as caribou. Although early contact with European explorers and fishers had minimal impact on the Beothuk, conflicts later arose, resulting in population movement and decline. The last known Beothuk survivor died of tuberculosis in 1829 (Cadigan, 2009; Janzen, 2008).

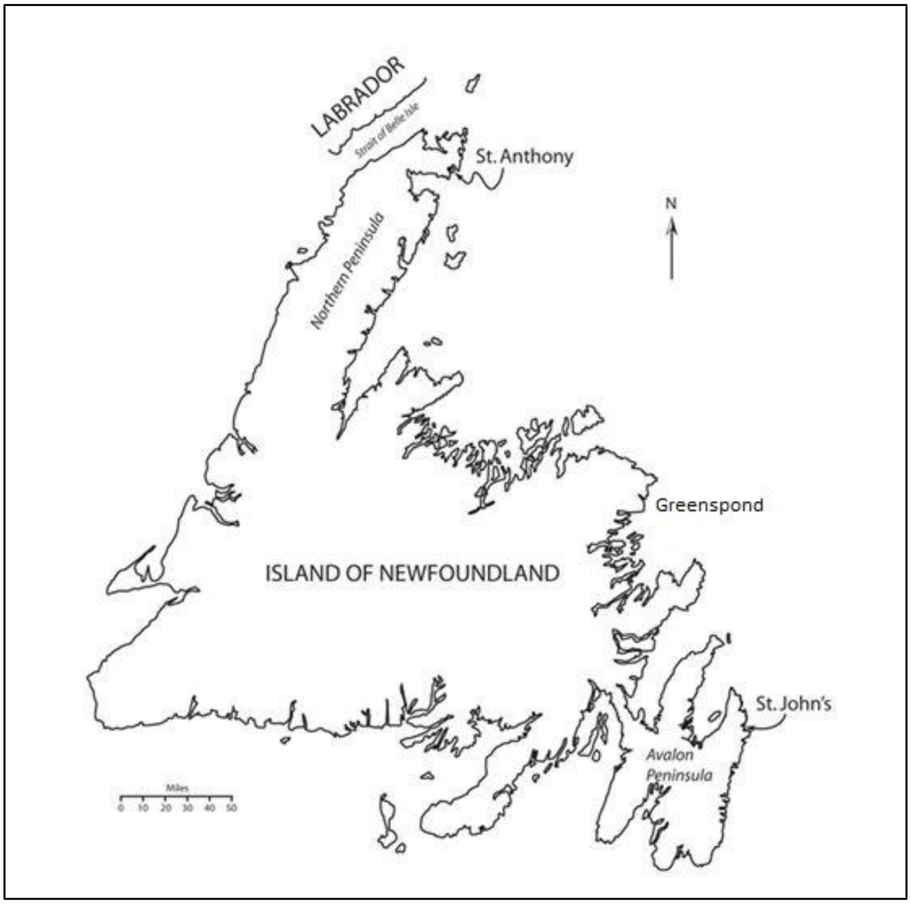


Figure 4.1. Map of Newfoundland indicating communities discussed in this research. The study community is part of the larger Greenspond region, located in Bonavista Bay along the northeastern coast; the provincial capital of St. John's is located on the eastern coast of the Avalon Peninsula. Research is also informed by previous work done for the community of St. Anthony, located at the tip of the Northern Peninsula. Figure modified from Orbann et al., 2014, Figure 6.1.

European contact began with the Vikings as early as the 11th century, but this contact was sporadic until the 16th century when French, English and Portuguese visitors began making frequent fishing expeditions to the region (Cadigan, 2009; Harris and Warkentin, 1974; Prentice et al., 1988). At various times, different countries were more prominently involved in this migratory fishery, with waxing and waning interest in the region often influenced by factors such as wars in other locations and priorities of trading partners and investors. Much of the competition was between France and

England, and it became apparent, particularly to English stakeholders, that settlement of resident fishers would help claim ownership of the island. However, concerns also persisted over ensuring the much larger migratory fishery retained access to the best fishing areas (Cadigan, 2009). Thus, many English policies also attempted to discourage and forbid permanent settlement (Cadigan, 2009; Harris and Warkentin, 1974).

Nonetheless, colonies were established in the early 1600s, although many of these quickly failed. King William's Act of 1699 served as a compromise between the migratory and resident fishers and outlined different rights for use of property (Cadigan, 2009). While legal ownership of land was not permitted until the early 19th century, private property was recognized among the inhabitants as early as the 18th century (Harris and Warkentin, 1974). Further, the French gave up most claims to Newfoundland with the Treaty of Utrecht in 1713, following the War of Spanish Succession, establishing English possession (Cadigan, 2009).

Many settlements remained small, due in part to the lack of women and children, until the 18th century. The population then grew rapidly, from estimates of 1200 people in 1675 to about 16,000 in 1764 (Cadigan, 2009; Porter, 1985). Demographic analyses suggest that the permanent population became greater than the temporary or semi-permanent population beginning in the 1780s (Handcock, 1977). Throughout the 1800s and early 1900s, various social and political efforts and reforms and the growth of manufacturers and other businesses contributed to the development of the population, as well as to an increasing distinction between the capital of St. John's and the poorer outlying communities (Cadigan, 2009).

By the time of the 1918 pandemic, the population of Newfoundland and Labrador, then classified as an independent dominion within the British Commonwealth, was about 255,000 people. Only about 4000 people lived in Labrador, and about 40% of the remainder lived in or near the capital city of St. John's on the Avalon Peninsula of Newfoundland (Figure 4.1). The rest of the population was largely dispersed among the coastal outports, which were relatively isolated geographically and often contained only a few to several families (Sattenspiel, 2011).

Household and Social Organization

The economic and subsistence focus on marine resources which determined settlement of the island also influenced the organizational and residential patterns observed within the outports, especially prior to Confederation. Notably, households tended to be patrilineal and patrilocal, and the small fishing crews were formed most frequently of fathers, sons and brothers (e.g. Firestone, 1967; Nemec, 1972; Queen and Habenstein, 1974). Ethnographic analyses of fishing communities suggest that the natural hierarchical structure and familiarity found among close relatives strengthened the bonds within the crew necessary for success in dangerous, uncertain enterprises (e.g. Nemec, 1972). Nemec (1972) argued that only family members could maintain secure bonds in the face of long periods of severe stress and close association. In further support of this argument, Nemec noted that effective kinship ties tended to be recognized only among closer (and thus, presumably more invested) relatives, while more distant relatives may have been known but held similar social relationships and obligations as non-kin in the outport.

Families commonly lived in nuclear households, though young couples and their offspring frequently lived with the husband's parents for some time after marriage before relocating to independent dwellings nearby (Queen and Habenstein, 1974). Particularly in smaller communities, men traditionally married women from outside the community but within the immediate region (Nemec, 1972). Upon the death of elderly parents, the house often passed to the son who lived with and cared for them, typically the youngest son (Firestone, 1967; Queen and Habenstein, 1974). Other household combinations included brothers and their families sharing a dwelling.

Whether families lived in nuclear or multiple-family dwellings, the extended family commonly worked together and shared ownership of fishing gear, berths and boats (Davis, 1983). All items related to fishing were inherited by sons equally, while women typically inherited only domestic goods (Davis, 1983; Nemec, 1972; Queen and Habenstein, 1974). Not all sons remained in the community or part of the fishing crew, however. For example, some men found alternative employment, e.g. in shops, while others emigrated from Newfoundland entirely. All individuals who remained at home contributed to the family income in some way; for example, women and children aided in processing catches on shore and sons engaged in other employment were required to contribute to the household (Nemec, 1972; Queen and Habenstein, 1974).

This pattern of shared labor, as well as relative economic independence for at least some women through education, inheritance and/or employment, suggests a degree of egalitarianism in outport life (see, for example, Davis, 1983; Porter, 1985). This notion of equality can be seen at the community level as well, and again may be related to the need for mutual assistance among individuals living in relatively dangerous, isolated conditions. Community members tended to have similar levels of income, occupation and education. The few categories of people who received higher status distinctions included clergy, merchants, medical professionals, and outsiders (Davis, 1983; Pocius, 1979; Porter, 1985). Differences could be seen, for example, during social calls, when higher-status individuals would be welcomed into the relatively finer but little used front rooms of houses. Generally speaking, all other individuals could visit neighbors' homes without invitation and gathered in the kitchens, which were the centers of activity (Pocius, 1979; Porter, 1985).

Additional opportunities for social interaction among community residents primarily were available through religious institutions and fraternal organizations. Many men, for example, were members of groups such as lodge associations, while women were frequently engaged in social and voluntary associations including church or exercise groups and service organizations (Davis, 1983; Murray, 1979). Additionally, "times" or parties were popular, particularly during the winter (Feltham, 1986). However, much of the time residents were engaged in the work activities described below.

Men's activities

The majority of adult males living in outports were employed in fishery activities, beginning at a young age and typically developing through several stages. Boys learned through imitation and engaged in light shore duties. From prepubescence to mid to late adolescence, males would perform early apprenticeship duties involving more tasks on shore as well as occasional boat trips. With advanced apprenticeship in the late teens to early twenties, young men took on full workloads at sea and on shore. Tasks focused on all necessary skills, such as navigation; maintenance; and knowledge of weather, tides, fishing grounds and equipment. However, these younger adults did not participate fully in decision-making by the crew. Full participation in decisions and work lasted from the early twenties to approximately 65 years of age. Elderly fishermen possessed less ability to contribute to productive labor and, from about the mid-seventies, were more likely to engage in shore duties and more casual shoreside observation (Nemec, 1972).

While specific activities varied in daily life, there were broad patterns of necessary work throughout the year; the discussion here is drawn from Feltham (1986) and refers particularly to patterns described for areas along the northeastern coast where the study community is located. For example, the early months of the year were generally considered restful compared to busier parts of the year. Much time was spent in mending nets and traps, carpentry work, cutting and hauling firewood, and other tasks. During this time, preparations also began for the annual seal hunt (Feltham, 1986).

Spring months shifted between preparing for and harvesting a variety of marine resources at different peak times, including herring, lobsters, salmon, and caplin. The busiest times of the year were around May and June when several species, most notably cod, were at their best. The strategies and demands of fishing varied based on the activities of these species. For example, during the peak caplin season of about three to four weeks in the early summer, men might only get a few hours of sleep a night. During this season, cod would feast on the caplin as well and become glutted and slow, allowing for relatively easy netting in shallow water. However, in early August, when cod began returning to the ocean banks, fishermen would leave home early enough to reach the grounds before daylight, fish until midafternoon, then return to shore to clean the catch and possibly go back out to fish until dark (Feltham, 1986).

This hectic activity tapered off by the end of August, and the next couple of months were spent washing and drying the catches, including cod brought back by crews who traveled to Labrador for the summer fishery. Fall months were also spent procuring supplies, harvesting potatoes and vegetables, and making other preparations for the winter months (Feltham, 1986).

As previously mentioned, men often engaged in two main additional employment activities that required travel from home and represented a major portion of fishers' annual incomes: the Labrador fishery during the summer and the spring seal hunt. Crews would leave for the summer cod fishery along the Labrador coast typically in May or early June (Coish, 1994). Occasionally, women would travel with the men to Labrador as cooks and aides. In some cases, whole families would relocate, although this appeared to be less common among fishers in the region encompassed in this study (White, 1996; White, 2002a; though see also White, 1997). For the seal hunt, men left home typically in late February to travel to ports, particularly St. John's, and the fleet sailed in March when seal herds were typically found along the northeast coast and sometimes as far to the southeast as the Grand Banks (Coish, 1994; Feltham, 1986; Ryan, 1994). Most ships were only out for five to six weeks, though the longest trip on record lasted for about fifteen weeks, from March 1 to June 15, 1884 (Harrington, 1986).

Since most activities were seasonal, men usually needed to find supplementary or alternative sources of income, and other employment opportunities included working in shops, government service, farming, lumbering, mining, medical professions, or teaching and clerical positions, depending on location and educational advancement (Colonial Secretary's Department, 1923; Murray, 1979; Queen and Habenstein, 1974). Many individuals also traveled for temporary or more permanent work in other areas, including St. John's and parts of Canada or the United States, especially Boston (Nemec, 1972; Ryan, 1994).

Women's activities

Historical and ethnographic descriptions of daily and seasonal activities in outport life tend to focus on the requirements of fishing and other activities of men. However, these sources also note the large contribution women made to the functioning of the household and community (e.g. Murray, 1979). For example, Feltham (1986) noted that women, who worked unceasingly throughout the year and often had fewer opportunities for socializing or travel outside of the community, deserved more praise than men. Porter (1985) argued that the boundary in the sexual division of labor was marked by the shoreline. In addition to domestic activities including gardening, childcare, making clothes and preparing meals, many women also participated in the fishery activities (Murray, 1979; Prentice et al., 1988; Porter, 1985; Queen and Habenstein, 1974). Women performed virtually all of the tasks required by the shore crew, including carrying fish from the wharf and cleaning and curing the catch. Overall, women's work effort is estimated to have contributed at least half of the family income (Murray, 1979).

Feltham (1986) also described typical activities of women in the Bonavista Bay region throughout the year. Daily schedules included preparing three meals and one tea for their families, and household chores such as washing and ironing clothes, and sweeping and scrubbing floors. Evening tasks included crafts such as hooking mats for floor coverings in the winter, or carding and spinning wool in the spring after sheep were sheared. Visits to relatives and friends were also common, particularly in the winter (Feltham, 1986).

In the late spring and early summer, activities included digging and sowing gardens but, by late June, women focused extensively on working in the shore crew virtually the entire day, in addition to other common household tasks with the assistance of older children. The pace of activity accelerated until late August before slowing until the end of the fishing season. However, in outports where many people participated in the Labrador fishery, the processing of the catch from this trip began in earnest towards the middle or end of August; in these communities, women and children also were required to do even more work while the men were away. Finally, the fall months were dedicated to tasks such as harvesting and preserving fruits and vegetables (Feltham, 1986).

Other employment opportunities, for example domestic servant positions, teaching and nursing, were available to women, particularly young and unmarried individuals (Kivimaki, 1937; Murray, 1979; Porter, 1985). Additionally, some women worked as midwives which often required staying with, and cooking and caring for, the family of the new mother for approximately a week (White, 2001b; White, 2002a). Generally speaking, women were involved in caring for sick individuals in their families and many knew some folk remedies (Murray, 1979; Porter, 1985). If another woman in the community was ill, her neighbors would help out the family (Feltham, 1986).

As mentioned above, members of the community were brought together through social activities and organizations as well. In many smaller outports, women who married into the community did not have the support or company of close kin, but they were often involved in associations like church groups and service organizations (Davis, 1983; Murray, 1979; Queen and Habenstein, 1974). For example, at least once a month, women in Bonavista Bay communities would thoroughly clean the church and school floors (Feltham, 1986).

Children's activities

Children also contributed to the running of the household from an early age by assisting in the shore crew and completing other chores and tasks. Boys, for example, often were responsible for shoveling snow, gathering firewood, fetching water, rounding up and feeding animals, and berry and vegetable harvesting. During the fishing season, boys too young to go out in the boats might clean and put away the catch (Feltham, 1986). Both boys and girls would run errands and deliver messages. While girls also were responsible for outdoor tasks like caring for animals, berry picking and bringing in vegetables, which children actually completed these chores varied depended on the required strength or weather conditions. Girls also were needed in the shore crews during the busy fishing season. Additional girls' chores largely included more domestic activities like setting the table, washing dishes, and caring for younger siblings. Older girls often were hired "into service" by friends and neighbors to watch small children while their mothers working during the fishing seasons (Murray, 1979).

Schools in Newfoundland were begun and run by churches with little government support through the time of the 1918 pandemic (Winsor, 1979). These schools were generally one room, though in the study region, two rooms were also common (Feltham, 1986; White, 1994b; White, 2002b). The teachers, frequently female, were responsible for perhaps 20-50 students (Feltham, 1986). The majority of students were between ages 7 and 12, and it was common for children to quit school in order to work as they grew older. Even those that continued in school were likely to have increased absences during busy parts of the season (Feltham, 1986; Feltham, 1987; Murray, 1979; White, 1994b; White, 1998; White, 2000).

Childhood in Newfoundland outports was not all work; both boys and girls were often free to entertain themselves with games and exploration. Play tended to occur outdoors, and the size of the groups varied depending on the activity, time of year and other factors like sex of the children. For example, boys tended to swim more often than girls. Other activities included playing games and sports, sledding and skating or visiting neighbors in the winter, and floating toy boats in the summer. Much of the time, especially in the summer when they might be called to work, children stayed close to the shore (Feltham, 1986; Murray 1979).

Social activities among adolescents often included courting behavior, such as conversing as they sat on opposite sides of a kitchen stove, walking home together from church or other houses, and “grassing” or sitting together – perhaps with more intimate interaction – in meadows. Teenagers were the most likely to have contact with others on nearby islands, particularly in the winter when “tickles” (narrow passages of water) could freeze over and allow for easier travel (Feltham, 1987). In the study community, it was also common for young women to walk along the roads at night, while boys sat on the fences and called out to them (White, 2001).

The Study Community: Newell’s Island, Greenspond

As noted, many of the general activities and organizational features discussed in the above descriptions apply to and are drawn from the study community district, but this region also has some unique aspects due to the area’s history as an important economic and administrative center. While the demographic characteristics used in this research are based on the population listed in the 1911 census for the now uninhabited Newell’s Island, this island was often considered part of the nearby town of Greenspond. Now a relatively small town of approximately 300 residents, Greenspond, once known as the “Capital of the North,” was strategically located for fishing, communication and trade, and the region reached a population of almost 2000 individuals at its peak at the turn of the 20th century (The Greenspond Come Home Year Committee, 1997; Smallwood and Pitt, 1981).

Located in the northern segment of Bonavista Bay, Greenspond is itself an island off the mainland of Newfoundland, and it is surrounded by many smaller nearby islands, including the study community of Newell’s Island as well as Batterton, Ship, Wing’s, Pig, Maiden, Groat’s and Puffin Islands (Figure 4.2) (The Greenspond Come Home Year Committee, 1997). Records show that settlers began fishing in this region in the late 17th century, with the population spreading to the nearby islands as it grew beyond the capacity of the local inshore fishery (Coish, 1994; Feltham, 1986). The early inhabitants were primarily from western regions of England, especially Dorset, Devon, Hampshire and Somerset. At its height, Greenspond was home to a resident doctor, magistrate, policeman and customs officer, as well as a post office, courthouse, and several merchants and other businesses (The Greenspond Come Home Year Committee, 1997). Trade with Great Britain, Italy, Portugal, Spain, Brazil, Greece and Ireland was cleared through its ports in the 19th century, and immigrants to Bonavista North generally landed there first (Feltham, 1986; Smallwood and Pitt, 1981). However, the population began to decline after World War I; this decline accelerated with deliberate efforts of the government in the mid-20th century to resettle more isolated or island communities into larger communities of the province (Feltham, 1986; Winsor, 1979).

Newell’s Island lies approximately 230 meters to the southeast of the island of Greenspond (Feltham, 1986). A report from the 17th century that mentioned a man “Nowill…who [had] more fish for his two boats” might suggest an origin for the name of the island (Winsor, 1979:16). Saunders (1960) also indicated that the island was named for an early settler. However, this name was not among the five main families most often connected to the island (Saunders, 1960; White, 1994b). In the 1857 census, there were 90 residents listed for Newell’s Island. This number varied over the years, for example dropping to 67 residents in 1874, and increasing by 1911 to 114 before declining again to 78 people by 1921 (Colonial Secretary's Department, 1923; Newfoundland's Grand Banks, 2013; White 1994c; White, 1999a, Winsor, 1979). People from the other nearby islands often went over to Newell's Island to gather caplin and keep sheep, which grazed freely away from gardens (White, 1999b; White, 2001a). While there was a request to build a causeway from Newell's Island to Greenspond in 1876, this never came to pass (Winsor, 1979). However, a ferry was in operation to transport people (White, 1995).

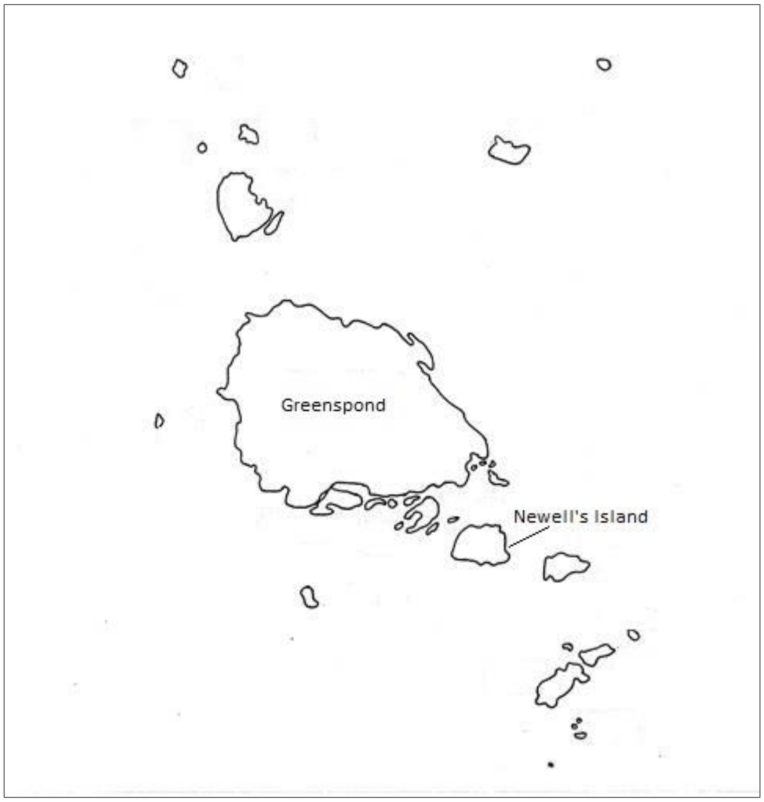


Figure 4.2. Greenspond and surrounding islands, indicating the relative location of the study community of Newell's Island. Image modified from White (1994a).

Greenspond itself was home to people in a variety of occupations, but the outlying islands were likely settled by people looking for unexploited fishing grounds and the majority of individuals were engaged in the fishing industry (Feltham, 1986). The Greenspond region contributed heavily to both the sealing industry and the Labrador fishery as well, with several schooners traveling to Labrador in the years around the time of the pandemic (Upward, 2005). The seal hunt was an important part of life in the area; people who remained behind during the season would hunt locally, while many more men went “to the ice” in large steamer ships (Coish, 1994; Feltham, 1986; Harrington, 1986). Many captains came from Bonavista Bay North; in 1906, 19 of the 25 captains were from this region (Winsor, 1985). Indeed, the residents of Newell’s Island were considered better off economically, as this island was home to several of the most successful sealing captains in Newfoundland (Saunders, 1960).

Despite perhaps biased reports from early missionaries that “moral conditions left much to be desired” in the “Sodom of the North,” religion also played an important role in the Greenspond area (Coish, 1994:57; Smallwood and Pitt, 1981:735). The churches were built on the main island of Greenspond, and residents of smaller islands generally traveled there for services, though resident clergy also were responsible for a circuit of communities throughout the larger region and often traveled to perform services and rites and visit congregants (The Greenspond Come Home Year Committee, 1997; Winsor, 1982).

The largest denomination in the area was the Church of England. The first Anglican church was built around 1810-1812 and was replaced in 1858 to accommodate the growing congregation, which approximately doubled between 1848 and 1858 (Coish, 1994; Winsor, 1982). By this time, services were held daily and twice on Sundays.

While attendance varied by season, it often increased before and during times of stress, such as during the seal fishery (Winsor, 1982). Methodism was the second largest denomination, with the mission established in 1862 and a church built by 1873 (Winsor, 1990). Additionally, the Salvation Army was introduced in 1885 (The Greenspond Come Home Year Committee, 1997). While never a large presence in Greenspond, there were also a few Roman Catholics. Altogether, these four religions had church buildings in Greenspond with a seating capacity of 1700 people in 1911 (Winsor, 1979).

The amount of interaction varied among the congregations. For example, despite differing views on social behaviors like dancing, intermarriage between Methodists and Anglicans in the Bonavista Bay area was common, though the wife would often convert upon marriage; marriages between Protestants and Catholics, however, were rare (Feltham, 1986; Feltham, 1987). Other contributions to Greenspond community life from the religious institutions included Anglican and Methodist church halls, a branch of the Church of England Women's Association, and in 1910, a total of five schools with seven classrooms (Winsor, 1979; Winsor, 1982).

As in other Newfoundland communities, children in Greenspond often quit school or attended inconsistently as they grew older, depending in part on their family's circumstances and the time of the year (White, 1994b; White, 1998; White, 2000). Nonetheless, while opinions vary in some sources (e.g. Feltham, 1987), education appeared to be valued in the region, even historically. For example, in 1902, the number of diplomas and certificates awarded in Greenspond was the second highest in Newfoundland after St. John's (Winsor, 1982).

Rules and regulations drawn up by the school board in 1843 indicated what typical school days might have been like in Greenspond. School would be in session from about 9:00 until 3:00 or 4:00, depending on the season, with a break for lunch. Lessons included devotional exercises and prayers, reading, spelling, writing, and arithmetic in approximate one hour blocks. Students were expected to attend Sunday School as well, if they were members of the church operating the school, but were allowed to attend Sunday schools at their respective churches if not. Sunday schools were held throughout the year, while regular weekly lessons stopped for three months during the summer fishery (Winsor, 1979).

At different points in the region's history, schools operated on the smaller islands as well as Greenspond itself. The first school on Newell's Island opened in 1868 in a renovated store. However, this school was closed around 1875 due to the small population and low enrollment on the island. By around 1879-1880, the population increased again, leading to the reopening of the school. Enrollment remained consistently around 20 students, and the school continued operating on Newell's Island until 1918 (Winsor, 1979).

Health and Medicine in Newfoundland

As discussed in Chapter 2, the second epidemiological transition, in which mortality from infectious diseases declined and the impact of chronic diseases increased, took place in many European and American regions around the turn of the 20th century. However, at the time of the 1918 pandemic, Newfoundland had not yet begun this transition, especially in the more isolated outports. Residents experienced many health problems during this time period; in addition to chronic conditions like tuberculosis and malnutrition, infectious disease epidemics swept the island. The second largest of these epidemics, after the 1918 flu, was the 1916-1917 measles epidemic, which was responsible for over 500 deaths. There were also recurring epidemics of pertussis, and an epidemic of scarlet fever in 1924 (Orbann et al., 2014).

Multiple efforts were made to improve both health and medical care in Newfoundland around this time. For example, a permanent Medical Health Officer was appointed in 1905, followed by the opening of a public health laboratory in 1906. Sir William MacGregor, governor from 1904-1909, began initiatives that included forming a volunteer anti-tuberculosis association, constructing a new tuberculosis sanatorium, creating a Department of Health and Education, implementing education programs, and improving sanitation, sewers and water supply systems (Baker and Pitt, 1984; Overton, 1998). In 1917, Mayor William Gosling of St. John’s began a child welfare movement that included promoting better housing conditions and appointing a community nurse to visit mothers and newborns (Godfrey, 1985).

One impetus in these health improvements came with World War I. Only approximately half of the men who applied to enlist were found to be fit for service. Combined with the flu epidemic occurring around the same time, this situation raised public awareness of health conditions and prompted many preventive measures (Nevitt, 1978). Further, the return of veterans suffering from tuberculosis led to the opening of a tuberculosis hospital in St. John’s. Similarly, the 1916 measles epidemic also had been a serious problem among the military population, and this led to opening of an infectious disease facility in St. John’s, which later moved to larger facilities and was used through the 1918 flu pandemic (Baker and Pitt, 1984).

Unfortunately, most of these efforts and funds to improve health were centered in St. John’s. The quality of and access to health care and related measures remained inadequate in the relatively isolated outports, due in part to poor transportation systems (Orbann et al., 2014). Several organizations and programs did attempt to reach the outports, including the Grenfell Mission (later the International Grenfell Association), a charitable organization begun by the British doctor Wilfred Grenfell to provide medical care and other services, especially to the residents of northern Newfoundland and communities in Labrador; and a nursing/midwife scheme planned by Lady Harris, the wife of the then-Governor in 1919 (Kennedy, 1995; Nevitt, 1978; Thomas, 1978). However, many locations were still understaffed or lacked medical personnel entirely. The Greenspond region did have a resident doctor who, like the clergy in the region, was frequently called upon to travel to other communities by boat or dog sled. Nearby communities including Newtown and Wesleyville also had doctors, and consultation among these different personnel occurred frequently. At the time of the 1918 pandemic, Greenspond’s doctor was Dougald Jamieson, who trained at Toronto University and was persuaded by Grenfell to practice in Newfoundland (The Greenspond Come Home Year Committee, 1997; *The Daily News,* 1955; White, 2002a; Upward 2005).

The 1918 Influenza Pandemic in Newfoundland and Greenspond

Newfoundland and Labrador were hit hard by the pandemic, with Labrador suffering much more severe mortality in at least some areas (Mamelund et al., 2013; Sattenspiel, 2011). On the island of Newfoundland, a total of 1885 people were listed in the provincial death records as dying from influenza, pneumonia and/or related causes during the pandemic, resulting in an average mortality rate of about 74.5 per 10,000 people. Mortality rates varied across different districts on the island, however, ranging from 28.6 to 109.3 deaths per 10,000 people. One explanation for this variability is proximity to resources in more populated areas; case fatality rate estimates are lowest in the Avalon Peninsula, where St. John's is located, and increase the farther away the district is from the capital city. In Greenspond's district of Bonavista Bay, the mortality rate was 64.5 per 10,000 people, with 38.5% of the deaths among individuals aged 15-44 years old (Sattenspiel, 2011).

Newfoundland experienced three waves of influenza, though the timing of these waves was generally later than the global waves frequently noted by researchers. Similar to other areas, the first wave was small, relatively mild and caused few deaths. This wave lasted from approximately May 1 to July 31, 1918. The second wave occurred approximately from September 10, 1918, to June 5, 1919. This wave was bimodal and severe, with the majority of the deaths occurring during it. The third wave was again rather mild but did not occur until the spring of 1920 (Sattenspiel, 2011).

The Newfoundland government attempted to mitigate the spread of the pandemic by implementing several control measures, including closing public gathering places such as schools, churches, and halls (Nevitt, 1978). Further, advertisements for sealing crews in 1919 warned that individuals who had recently recovered from influenza would not be cleared by doctors to sign up (e.g. the *Evening Telegram*, 1919a and 1919b). Some of these steps appeared to be relatively successfully followed, while other actions were ignored. For example, ships with sick sailors were quarantined in St. John's, but no official actions were taken that interfered with regular shipping schedules (Mamelund et al., 2013).

Greenspond was struck by the flu especially hard, according to a report to the Diocesan Magazine which indicated that church services were either reduced in size or cancelled entirely during the Advent and Christmas season (The Literature Committee of the Diocesan Synod of Newfoundland, St. John's, 1919; Winsor, 1982). The first report of flu in Greenspond, claiming seven to date and two current cases but no deaths, appeared in the October 29, 1918, issue of the *Daily News*. Subsequent weekly reports to the Colonial Secretary indicate an increase in cases in late November through mid-December. The magistrate in Greenspond telegraphed for aid on December 9th, reporting 250 cases and "whole families…down with the disease, and…no assistance" (Provincial Archives of Newfoundland and Labrador, 1918). By December 17th, the local doctor reported 400 cases to date and 6 deaths, but by December 24, reported the epidemic had subsided and there had been no further deaths (*The Daily News*, 1918a; *The Daily News*, 1918b). Overall, influenza and pneumonia deaths listed in mortality records total eleven deaths for the Greenspond region (Provincial Archives of Newfoundland and Labrador, 1918-1920).

This information about the local pandemic experience, as well as features of life in 20th century Newfoundland in general and Greenspond in particular, are used in this project to inform and validate epidemiological computer simulation models. The following chapters will first describe modeling theories, techniques and applications, and then describe how the archival, historical and ethnographic data sources were used to develop the models used in this study.

CHAPTER 5 – MODELING IN ANTHROPOLOGY AND EPIDEMIOLOGY

Models are used across multiple disciplines and may include simple diagrams or verbal descriptions, mathematical processes such as regression or differential equations, or complex computer simulations. Broadly speaking, models provide a simplified representation of a phenomenon or system of interest. Research using models may try to understand causal relationships or interactions among different factors influencing the system, explain or predict outcomes, or identify unknown parameters or elements. When using models, researchers must balance the inclusion of sufficient details with the need to avoid overwhelming complexity, and also must choose a modeling strategy appropriate to research questions and available data and resources.

Strategies for modeling epidemics generally fall into three categories: statistical, mathematical and computer-based simulations. Statistical methods include regression or correlation, time series, and geographical or spatial analyses. Examples of mathematical approaches are population projections from life tables, and compartmental models that estimate progression of disease through different stages. A major difference between these two strategies is the direction from which they approach analyses. Statistical methods begin with data and attempt to fit mathematical relationships to explain and understand those data, while mathematical models use theoretical assumptions and characteristics of the system of interest in an attempt to generate data that reproduces empirical observations (Sattenspiel, 2003). While these types of models are still used today, advanced computing power and sophisticated modeling programs have led to increased application of simulation models, like the agent-based and social network models used in this research. Many simulation models of infectious disease transmission are based on compartmental models, a broad class of mathematical models. In particular, disease simulations are often variations of the SIR model. This chapter first describes this fundamental epidemiological model, followed by a brief history of simulation models; the rest of the chapter then discusses the theoretical foundations and representative applications of agent-based and social network models in anthropological and epidemiological studies.

The SIR Model

In SIR and other similar epidemiological models, the model population is allocated to different compartments that reflect simplified stages informed by the biological nature of the pathogen or disease in question (Figure 5.1). The portion of the population that is in the susceptible (S) stage is at risk of infection, while the infectious (I) stage contains the proportion of individuals who are capable of transmitting the pathogen, and the recovered or removed (R) compartment includes the portion who have completed the disease process. The durations of these stages vary for different kinds of infections, and they do not necessarily correspond with clinical terms used to describe disease progression. For example, individuals may become infectious before they enter the symptomatic stage or remain infectious after they stop presenting symptoms. The most important assumptions of this basic SIR model are that recovery results in permanent immunity, that the latent period, i.e. the duration of time after exposure before an individual becomes infectious, is so short it can be ignored, and that the population is closed; i.e., there are no births, deaths, or migration (Sattenspiel, 2009; see also Anderson and May, 1991; Keeling and Rohani, 2008; Kermack and McKendrick, 1927).

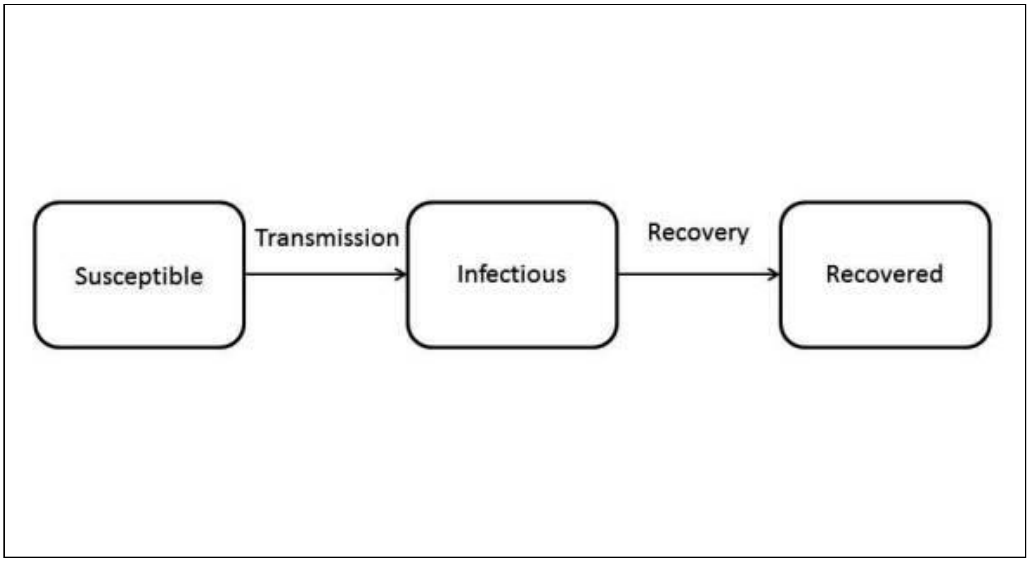


Figure 5.1. Basic structure of the SIR model. Transmission is influenced by social factors affecting the rate of contacts among individuals and biological factors that determine whether a contact results in transmission of a pathogen. Recovery is assumed to occur at a constant rate.

The SIR model incorporates processes that govern the flow of the population from one compartment to the next. Like many statistical and mathematical approaches, the simplest SIR model assumes that the population is sufficiently large and homogenous so that individual variation and random factors do not impact disease processes. Further, the portion of the population that moves from one compartment to the next each time unit may be a fraction rather than full integers (Sattenspiel, 2003; Sattenspiel, 2009). Usually features of different SIR models, such as the overall system, changes within compartments, and the transition between compartments, are controlled by mathematical processes such as differential equations. For example, transmission is considered a function of the average number of contacts made by susceptible individuals and the probability that a contact actually results in transmission of the pathogen; this function is also referred to as the transmission rate or parameter. Therefore, the rate of new infections reflecting the transition from the susceptible to infectious compartments can be modeled as the product of this transmission rate, the number of susceptibles, and the probability that a contact is with an infectious person. In the simplest form of the model, the recovery flow is simply modeled as a constant that is the reciprocal of the average duration of infection (Sattenspiel, 2009)

Extensions to the simple SIR model increase complexity in two broad ways. First, the type or number of compartments can be altered to reflect the biological dynamics of the disease of interest. Diseases with reasonably long latent periods, for example, can be studied with SEIR models that add an exposed (E) stage. Other variations (e.g. SIS) include allowing individuals to become susceptible again, rather than entering the “R” stage. Second, modelers can increase complexity by adding additional processes or structure to the population. For example, populations may be divided into smaller subgroups that are internally homogenous but have different rates of infection, recovery and other changes compared to other subgroups. Additional processes, such as births and deaths from other causes, can be considered, and randomness (stochasticity) can be added (see Sattenspiel 2009 for a thorough discussion of extensions to the SIR framework).

Simulation Models

As models become increasingly complex, it becomes difficult or impossible to adequately determine and analyze disease progression mathematically. Additionally, assumptions such as random mixing among homogenous members of a population are often restrictive and unrealistic, particularly for small populations traditionally studied by anthropologists (Sattenspiel, 2003). Computer simulation models, which often are not explicitly based on mathematical equations, offer a solution to these and other limitations. One of the earliest classes of simulation models is Monte Carlo simulations, in which model processes, e.g. changes in status, are determined by comparing results of random number generators to predetermined probabilities (Sattenspiel, 2003; Sattenspiel, 2009). Monte Carlo simulation models were used to study, for example, community size and measles epidemics (Bartlett, 1961), and the spread of the 1957-1958 Asian flu among different mixing groups including schools and neighborhoods (e.g. Elveback, 1971; Ewy et al., 1972; Elveback et al., 1976; Ackerman et al., 1984).

Consideration of discrete groups was one common method used in early simulation models. For example, Sattenspiel (1987) used a simulation model to study the spread of hepatitis A in Albuquerque, New Mexico among neighborhoods and day care centers. An alternative approach was to visualize model populations as individuals located at points of a lattice or grid (e.g. Bailey, 1967; Bartlett, 1961; Kelker, 1973). As simulation models developed, the types of diseases studied also grew, including parasitic diseases (e.g. De Vlas et al., 1996; Plaisier et al., 1990). Additionally, questions related to sexually transmitted diseases prompted the development of simulation models incorporating social networks (e.g. Kretzschmar and Morris, 1996; Morris and Kretzschmar, 1997) More sophisticated and recent simulation models, like agent-based and social network models, draw on similar ideas as these earlier examples (e.g. stochasticity and individual variation, as well as the SIR framework) to expand knowledge and understanding of epidemiological processes.

Agent-Based Models

Agent-based models move beyond the limitations of many population-level approaches that assume individual variation is unimportant, and instead explicitly consider discrete units or agents with their own characteristics and rules for behavior or disease progression. The individual units in these simulation models may be microorganisms, people, animals, households or other types of entities that can be given unique attributes or otherwise considered as independent wholes. Some researchers distinguish between individual-based models, in which the entities simply follow rules of behavior, and agent-based models, in which agents are able to learn new information from the surrounding environment as it changes over time, share information with each other, and change behaviors accordingly (Gilbert, 2008). However, this distinction is becoming less common in modeling literature (Railsback and Grimm, 2011). Generally speaking, regardless of how individuals or agents are conceptualized, the aim of agent-based models is to gain insight into how system-level outcomes emerge from individual-level behavior.

At the most basic level, these models consist of three components: a set of agents, the environment, and rules of behavior. The agents exist in the environment or world, and a set of rules governs how agents interact with each other and with the environment over the course of a simulation. Researchers may expand on these basic components by increasing their complexity, variety and number. For example, the world may range from a simple grid to one that includes detailed geographic information like resources and realistic topography. Different kinds of agents may be modeled, each with their own sets of rules. Further, agent-based modeling techniques enable relatively easy incorporation of non-random mixing patterns and various forms of stochasticity (Epstein and Axtell, 1996; Gilbert, 2008).

Because of the focus on individual behavior and relationships, agent-based models are well suited to address research questions in anthropology and other social sciences. For example, models have examined the influence of social relationships and marital status of others in the population on age-at-marriage patterns (Billari et al., 2008), the formation of dominance hierarchies in non-human primates (Hemelrijk, 2002; Hemelrijk et al., 2005), and the development of ceremonial exchange systems such as the Kula (Ziegler, 2008). Models of prehistoric or archaeological phenomena have addressed topics such as the effects of climate change and other factors on marine resource exploitation (Morrison and Addison, 2008), political consolidation in the Lake Titicaca basin (Griffin and Stanish, 2007), and population and settlement patterns in the American Southwest (e.g. Axtell et al., 2002; Gumerman et al., 2003; Swedlund et al., 2014).

Numerous studies in anthropology and other fields have used agent-based models to explore disease-related processes. These models approach epidemiological questions from multiple scales. For example, some studies focus on large, urban settings or broad geographical regions including global air travel (e.g. Das et al., 2008; Ohkusa and Sugawara, 2009; Stroud et al., 2007) while others have modeled nosocomial infections within hospitals (Hotchkiss et al., 2005) or even situations where the agents are biological components of the immune system (Segovia- Juarez et al., 2004). Models of influenza in general and the 1918 pandemic in particular have looked at factors such as the effect of community structure, mobility, and important social institutions on disease spread (e.g. Carpenter and Sattenspiel, 2008; Dimka et al., in press; O'Neil and Sattenspiel, 2010; Orbann et al., 2014). A variety of other diseases and modes of transmission have been studied with agent-based models, including the spread of vector-borne illnesses like trypanosomiasis and dengue fever; the interactive effects of land use, water contact behaviors and socioeconomic factors on transmission of schistosomiasis; and other health conditions related to water quality (Demarest et al., 2013; Hu et al., 2010; Muller et al., 2004; Reiner et al., 2014). For example, Muller et al. (2004) used a spatially explicit model to demonstrate that prevalence of human African trypanosomiasis is influenced by the density of humans and the number of infected tsetse flies in particular locations. Reiner et al. (2014) argued for the importance of including human social interactions when modeling vector-borne illnesses, instead of simply focusing on spatial factors.

A common goal of epidemiological research is the evaluation of potential preventive or mitigation strategies such as vaccination or quarantine (e.g. Ciofi degli Atti et al., 2008; Eidelson and Lustick, 2004; Milne et al., 2008). For example, Milne et al.

(2008) examined the potential effects of various social distancing measures including school closure and work non-attendance; results indicated that if multiple measures are applied early and continuously, they can be effective in preventing transmission. Eidelson and Lustick (2004) tested different vaccination strategies and found that the effectiveness of certain approaches depends on timing, early identification of cases, and levels of herd immunity in the population.

Recent models have considered the control or prevention effects of individual changes in behavior rather than community-level interventions. Kumar et al. (2013), for example, found that access to and use of paid sick leave for employees during an influenza epidemic could reduce workplace transmissions between 25 and 39 percent, depending on the number of available days. Similarly, Williams et al. (2011) found that the severity of an epidemic is determined by the degree of individual compliance with interventions (e.g. home isolation, reporting to a treatment center) in a bioterrorism model of deliberately released pneumonic plague.

As these examples demonstrate, agent-based models can be effectively used to address a variety of epidemiological questions. The majority of studies incorporate some form of policy or prevention recommendations, but others also emphasize investigating and understanding the general system of disease transmission under different circumstances or conditions. The major benefit of agent-based simulation models over statistical or mathematical methods is the enhanced ability to include individual heterogeneity, randomness, and spatial considerations. These features allow for additional or even new insights into the spread of epidemics that are not possible to observe with traditional methods.

Many modelers have taken advantage of increased computer power to simulate large-scale contemporary or urban populations (Eubank et al., 2004; Ferguson, et al., 2005; Longini et al., 2005; see also Milne et al. (2004), who refer to their study community of approximately 30,000 people as “small”). Accordingly, simplifying assumptions about agent classes, behaviors, and community structure are still required. Therefore, it is unclear how many models actually take full advantage of individual (or as distinguished above, agent)-based approaches. Further, results for such large model populations may not be relevant or appropriate for the small, traditional communities often studied by anthropologists. Even with smaller populations, however, the detailed complexity of agent-based models also comes with a cost, as they require sufficient data to reasonably support assumptions and assign individual characteristics and behaviors to agents. Tracking individual attributes, controlling agent behavior, and recording model outcomes consequently result in computationally expensive models compared to more traditional strategies.

Social Network Models

Social network models can be considered a subtype of individual-based models that explicitly consider relationships between people or other types of discrete units (Knoke and Yang, 2008). These models are visualized as sociograms (first used by Moreno, 1934), i.e. graphs where the individuals are represented as nodes, while lines (varyingly called links, edges, or ties in different disciplines) connecting nodes indicate a relationship between the pair. Relationships may be undirected or directed to demonstrate reciprocity or lack thereof, or weighted to reflect the strength or duration of a connection (Knoke and Yang, 2008; Newman, 2010).

The first commonly recognized problem solved by social network visualization and analytical techniques (or more broadly, the area of mathematics known as graph theory) is the famous Königsberg bridge problem, analyzed by Leonhard Euler in 1735. The town of Königsberg, Germany, was formed by two sides of a river and two islands; these four sections were linked by seven bridges. Euler used graph theory to demonstrate that it was impossible to reach all four sections by crossing each bridge only once (see, for example, Alexanderson, 2006; Gribkovskaia et al., 2007). Other early applications of graph theory have been applied to questions related to electrical networks, organic chemistry, and geography or maps (Roberts, 1976). According to Sattenspiel (2009), extension of these ideas to social science research is frequently attributed to Harary and Norman (1953) and Harary et al. (1965). Dunn and Janes (1986) credit pioneering anthropological works (e.g. Mitchell, 1969) and subsequent developments by epidemiologists (e.g. Berkman and Syme, 1976; Pilisuk and Froland, 1978) for the application of social network concepts to health-related research.

Perhaps the most important aspect of social network approaches is the theoretical perspective recognizing the role of interdependency between individuals. Relationships enable the sharing or control of information or resources, and thus are the underlying foundation for social, political and economic structures at larger scales. Thus, the relationships themselves are the units of analysis in social network models (Knoke and Yang, 2008; Wetherell, 1998). This approach differs from traditional analytical methods, which typically focus on the attributes of individuals. Consequently, traditional statistical methods that require assumptions of independence are frequently inappropriate for analyzing network data (e.g. Knoke and Yang, 2008).

Methods on how to analyze full networks, as well as specific regions within larger networks, have been developed. Such measures frequently aim to identify important or central nodes, the ease or speed with which something may reach different nodes, and the overall structure of networks. For example, a node's degree is the count of how many links it has, and based on these counts, overall measures on the full network such as average degree or the degree distribution can be calculated as well. Different measures of centrality identify nodes that, for example, serve as hubs between other nodes or sections of the network. Clustering measures aim to quantify subgroups of nodes that are all connected to each other, while density measures determine the proportion of links relative to the total number of possible connections (e.g. Knoke and Yang, 2008; Newman, 2010). As these measures suggest, networks can be constructed and analyzed from the perspective of specific, individual nodes (i.e. egocentric networks) or from whole or complete networks. The chosen approach might reflect the research questions and design, as well as the limitations and methods of data collection.

A variety of approaches are used to construct social networks for research purposes. For example, empirical observations or surveys are sometimes used to estimate the average number of partnerships or contact rates (e.g. Cauchemez et al., 2011; Edmunds et al., 2006; Mossong et al., 2008; Salathé et al., 2010). Alternatively, hypothetical or idealized structures are sometimes constructed. These structures include lattice models, which are essentially grids where each node is connected to each of its nearest neighbors, and small world models, where most nodes are linked to nearby nodes but a few long-range links are also present (Newman, 2010; Sattenspiel, 2009). Social network data have even been gleaned from web sites such as Facebook and Twitter (e.g. Harrigan et al., 2012).

Previous research has also used historical and archival data to construct social networks of communities. For example, Cline (2012) demonstrates the applications of social network analysis to historical research through two illustrative examples of individuals associated with Philip II of Macedonia and Pericles. Instigated by recent terrorist activities performed by groups such as Al-Qaeda, Crossley et al. (2012) tested hypotheses regarding the development of covert organizations and movements by linking together arrest records of suffragettes in the United Kingdom from 1904 to 1913. Alexander and Danowski (1990) mined letters written by Cicero to look at the structural positions of senators and knights in Roman society, while Padgett and Ansell (1993) combined data on wealth, status and neighborhood of residence, with marriage, economic and patronage networks of elite families in Florence to explore the rise of the Medici family.

Social network models have been used to study topics relevant to anthropology and other social sciences, including decision making, social support, and the diffusion of innovations, beliefs and gossip (e.g. Ellwardt et al., 2012; Fowler and Christakis, 2008; Mertens et al., 2012; White, 2013). Researchers have employed social network methods to study nonhuman primate societies (e.g. Sade and Dow, 1994), trade and transportation routes for ancient Rome (Graham, 2006), settlement and material culture distribution in the American Southwest (Mills et al., 2013), and the interactions and organization of various institutions in response to the September 11, 2001, terrorist attacks (Schweinberger et al., 2014).

Generally speaking, social network theories and techniques are applied to epidemiology in three ways: determining the effects of overall network structure on the spread of disease, the impact of specific network features (e.g. clustering) on the likelihood of epidemics and rate of spread, and the influence of particular nodes based on relative position in the network (Sattenspiel, 2009). The development of modern and efficient techniques for applying social network theory and analyzing data is due in strong part to the challenges raised in understanding and combating the HIV/AIDS pandemic (see, for example, Morris, 2004). Research on the spread of sexually transmitted infections has looked at, for example, the effects of concurrent vs. monogamous partnerships (e.g. Goodreau et al., 2012; Morris and Kretzschmar, 1997) and risk behavior such as needle-sharing (Rothenberg et al., 1998) on HIV transmission. Social network analyses are applied to a variety of other epidemiological concerns and diseases as well. For example, studies have looked at the transmission of infectious diseases among livestock and domesticated animals (e.g. Ciccolini et al., 2012; Davies, 2002). Salathé, et al. (2010) used wireless sensors to record contacts among American high school students to investigate the potential spread of influenza. Other studies focus on the positive and negative roles of social relationships on health care choices, symptoms and behaviors (e.g. Christakis and Fowler, 2007; Gage, 2013; Hatzenbuehler et al., 2012; Zhang et al., 2015). Many studies also investigate the impact of preventive or control methods such as individual behavior change, vaccination rates and school closure (e.g. Barrett et al., 2011).

At a more theoretical level, studies have examined the effects of network properties on disease spread. Research has shown, for example, that networks with more clustering tend to result in slower diffusion, more frequent burnout and epidemics of smaller overall size, because the disease gets trapped within clusters and cannot escape to the larger network (e.g. Badham and Stocker, 2010; Eames, 2008; Rahmandad and Sterman, 2008; Salathé and Jones, 2010; Volz, 2010). However, Newman (2003) and Miller (2009) have found that clustered networks may affect the growth rates of epidemics by reducing the epidemic threshold, or the critical population size needed to sustain an epidemic disease. A related concept, R_0 (the average number of secondary cases in an otherwise susceptible population) is also used frequently. Values of R_0 above 1 are needed in order for epidemics to occur. Newman (2003) proposes that redundant connections in clustered networks allow for multiple potential paths of infection even at low transmission probabilities. Further, Badham and Stocker (2010) caution against analyzing structural properties of networks such as clustering independently of other properties such as assortativity (essentially, the tendency for nodes with similar degrees to share a link), as the different network features may be related or produce cumulative effects, and thus any observed outcomes may be attributed to the wrong measure.

Research has also focused on individual variation in the risk of transmission. For example, Meyers et al. (2005) considered the role of “superspreaders” or nodes responsible for a disproportionately large number of infections. Other work has looked at the effect of heterogeneity in weights of links. Moslonka-Lefebvre et al. (2012) argued that traditional approaches assuming a constant risk of transmission of sexually transmitted infections per partnership is unrealistic; instead, incorporating weighted links in models to more realistically reflect variation in partner activity produces outcomes that are consistent with empirical data. Zhu et al. (2013) modified link weights by decreasing the strength between two connected individuals as the disease develops; this study found that adapting weights in response to epidemics may reduce effects such as speed and size but cannot stop epidemics or change epidemic thresholds. Eames et al. (2009) argued that weighted network models might improve intervention recommendations, particularly for diseases spread by close contact, but that full or complete data on social mixing is not necessarily required to optimize model results.

Social network models are of particular relevance for diseases that can be relatively easily traced from one case to the next, as with sexually transmitted diseases. However, as the previous discussion indicates, many studies rely on survey data or computer algorithms to generate networks, which may call into question whether these networks can be generalized to other populations or are realistic representations of actual social networks. Data collection and concerns are perhaps of even greater concern than they are for agent-based models, as social network models require extensive information on the individuals involved, as well as the relationships between them. Data collection and privacy concerns may present difficulties, and researchers are often limited in sample size or are required to specify finite group boundaries in terms of space, time or the explicit type of relationship to consider (see, for example, Eames et al., 2015; Mikolajczyk and Kretzschmar, 2008).

Comparisons of Modeling Strategies

At a fundamental level, different model designs require certain structural and theoretical assumptions. While previous studies have frequently explored the effects of changing variables within a specific model design, explicit comparisons of broader strategies, such as between agent-based and social network models or mathematical and simulation models, tend to be less common. Additionally, articles describing and comparing different techniques may be more conceptual in nature. For example, El-Sayed et al. (2012) discussed the relative strengths and weaknesses of agent-based models and social network models in epidemiological research, including data requirements, generalizability, and the scope or nature of the specific questions. Although this analysis provided an overview of previous research and findings in the field, no systematic comparisons of actual models were presented. These comparisons are further complicated by variation in how models are described (see, for example, Barrett et al., 2011 and Zhang et al., 2012), since as mentioned, social network models can also be considered a subclass of individual- or agent-based models.

Research that has explicitly compared model structures includes analyses by Fefferman and Ng (2007), who explored the differences between static and dynamic networks, i.e. whether the links between nodes are allowed to change during the course of a simulation. Results indicated that incidence of disease tends to be larger in dynamic network models, as new links continuously alter the path of transmission. Similarly, Risau-Gusman (2012) used a dynamic network model to demonstrate that static networks can underestimate epidemic thresholds.

Other comparative studies have considered network models and more traditional modeling assumptions and structures, such as simplified mixing patterns. For example, Bansal et al. (2007) and Duncan et al. (2012) both compared empirically derived or more realistic network structures to networks based on simpler assumptions such as mass-action or homogenous mixing assumptions. Bansal et al. (2007) concluded that the choice of model depends on the contact network of the population under study, and homogenous mixing models may be suitable for certain types of populations. Duncan et al. (2012), however, found that observed contacts among cattle herds were structurally very different from random mixing networks and thus produced significant differences in disease spread. Similarly, Smieszek et al. (2009) also compared two network models, which differed in whether contacts were regular or random. This study found, for example, greater differences between the two models at low estimates of parameters such as number of contacts per day and transmission probability, and that the addition of a few random contacts greatly increased the chance the epidemic would spread between otherwise unconnected components of the network. Machens et al. (2013) create a series of networks from the same underlying data source, including models containing full and detailed information of dynamic contact patterns, models with heterogenous link weights, models with homogenous mixing, and models based on contact matrices corresponding to different classes of individuals. Their results suggest that intermediate complexity is often sufficient to capture epidemic processes, but that average or homogenous contact patterns are not refined enough.

Additionally, researchers have considered the similarities and differences between agent-based and mathematical models, such as those based on differential equations. For example, Sattenspiel (2007) demonstrated that individual-based models can provide additional insight and explanation for disease spread, particularly when researchers wish to consider within-community factors, relative to models where transmission is governed by ordinary differential equations. Similarly, Ajelli et al. (2010) found that a stochastic agent-based model was useful for understanding intra-population factors and estimating the impacts of disease at a more local level; the metapopulation model it was compared to, however, represented the connections between global subpopulations and thus was better for identifying major transportation routes and how epidemics may be introduced to different regions worldwide. Bobashev et al. (2007) argued that a combined approach may be used to address practical concerns such as data complexity and computing requirements while still trying to optimize results. Their hybrid model incorporated both agent-based and equation-based features to account for assumptions and levels of certainty at different stages of an epidemic simulation.

Combining different methods is one challenge for future development of modeling infectious diseases. Pellis et al. (2015) have called for increased consideration of other areas of analysis in network modeling, including incorporating and understanding the effects of heterogeneity (for example, regarding parameter estimation), weights of network edges, dynamic networks, epidemic interventions and more strongly connecting models to empirical epidemic data. Riley et al. (2015) discuss the need to incorporate spatial concerns into more traditional network model development, such as including mobility or long-distance interactions and identifying the most appropriate resolution or level of spatial analysis to consider when testing potential interventions. Similarly, articles in a special issue of the journal *Social Networks* demonstrated the new insights as well as potential difficulties that can be raised by combining network and spatial data and modeling strategies (see, for example, adams [sic] et al., 2012).

This project contributes to insights gained from previous work on model development and comparisons, and begins to address several of the challenges mentioned above. First, an agent-based model and a social network model are explicitly compared, using behavior and relationships derived from ethnographic and archival sources to estimate realistic contacts. As described in more detail in the following chapter, the agent-based model emphasizes behavior and movements of different members of the study community to important social spaces. The social network model implicitly incorporates these spatial interactions but emphasizes important relationships among individuals, such as members of the same household or children who attend school together. These comparisons allow for consideration of static and dynamic network behavior and incorporation of weighted links, which as discussed above, have been demonstrated to produce noticeably different effects on the likelihood of epidemics, as well as epidemic size and timing. Further, while certain simplifying assumptions are still required, these models draw upon detailed sources to create a realistic, small community and thus provides insight into outcomes for populations traditionally of interest to anthropologists, which may be different than outcomes observed in models focused on large urban cities in more developed regions.

CHAPTER 6 – METHODS

As indicated in previous chapters, this project explores questions related both to the factors influencing disease transmission within small communities that might explain observed outcomes during infectious disease epidemics, and to the theoretical and practical assumptions that underlie the tools and frameworks used for studying population health. To investigate these questions, two computer simulation models have been created for comparison to each other and evaluation of hypotheses. The agent-based model emphasizes individual behavior through movement of agents to important social spaces according to a designated schedule, while the social network model lacks this explicit spatial and, to an extent, temporal framework. Instead, it focuses on important relationships among individuals. To facilitate comparisons, the models are designed to be as similar as possible in other features. However, the structural assumptions result in an essential difference between the two models: the contact network in the social network model is predetermined and mostly static or constant throughout a simulation, whereas the contact network in the agent-based model is dynamic and emerges from the behavior of individuals over time. This chapter describes the process of collecting and evaluating data and how those data were used to build both models. The design and functioning of the models are also described, followed by a discussion of procedures used to ensure the models produce realistic and reliable results. Finally, the methods used to address the specific research questions outlined in Chapter 1 are briefly presented.

Data Collection and Evaluation

Both models are supported by data from print and online primary and secondary sources. Data collection was aimed at gathering three broad categories of sources: genealogical information, including vital statistics and parish records, to support family reconstitution activities described below; detailed descriptions of daily lives and activities in the study community to inform modeled behaviors; and records providing information on the general health of the community and its experience during the 1918 pandemic to assist in estimating model parameters. Many of these sources have been drawn upon and cited in previous chapters, particularly Chapter 4, although special acknowledgment must be given to the *Greenspond Letter*, a historical newsletter edited by Linda White for the last twenty years that frequently features interviews with current or former residents and copies of archival documents of historical and genealogical interest.

I spent five weeks in Newfoundland during the summer of 2012, with the majority of the time dedicated to data collection in the capital of St. John's at the Centre for Newfoundland Studies in the Queen Elizabeth II Library of the Memorial University of Newfoundland and at the Provincial Archives of Newfoundland and Labrador ("The Rooms"). I also traveled to the community of Greenspond for approximately five days to become familiar with the area; this visit included a trip to the community museum located in the former courthouse, and an excursion to Newell's Island itself where I was able to see the remnants of several gravestones. While I was in Greenspond, I met several community residents who volunteered information about the history of the region, reinforcing data collected via other means. Both before and after this fieldwork, additional data and insight have been gleaned primarily from ethnographic literature and online sources (notably Newfoundland's Grand Banks, 2013), as well as a continued subscription to the *Greenspond Letter* and membership in the Greenspond Historical Society Facebook page.

Studies incorporating historical and archival documentation introduce several potential sources of error. For example, information recorded at the time may have been inaccurate or intentionally biased or misrepresented. Further, not all information is recorded in the first place, particularly in regions where there is a high level of illiteracy. Records may be lost or damaged over time or be confidential or otherwise inaccessible to researchers (e.g. Barber and Berdan, 1998; Hollingsworth, 1969). Therefore, the quality of data must be considered carefully, particularly as it relates to interpretations and implications of results. In this research, the major potential sources of error are inaccurate or incomplete records used to reconstruct the model population and to estimate disease-related parameters such as the mortality probability, and biased reports of daily life and community structure used to determine behaviors of modeled individuals.

To minimize concerns related to the first potential error, multiple sources (e.g. census and parish records, and references to individuals and families in historical monographs and published interviews) were used wherever possible to reinforce decisions and assumptions made about relationships between individuals. The most common discrepancies observed among different records include minor variations in spelling of names or years of events like births and marriages. As this study generally considers demographic subgroups rather than specific individuals, these minor differences are not expected to impact the validity of results. The process of evaluating and using different records to construct the model population is discussed in more detail below.

Epidemic data applied to this research include deaths from pneumonia and influenza listed in vital statistics records at the provincial archives, and the number of cases reported to the Colonial Secretary's office during the pandemic. Because of the presence of trained medical personnel in the region, it is reasonable to assume that records of deaths attributed to respiratory illnesses are accurate and reflect pandemic cases. However, the number of cases is less certain. The reported cases and the majority of the deaths were recorded only during the time the second wave of the pandemic struck the island of Newfoundland. It is unknown whether or to what extent Newell's Island or the larger Greenspond region were affected by the other waves. Similarly, the population at risk was estimated, as there are no census data from those exact years. Nonetheless, model parameters calculated from these data fall within ranges reported in other literature for pandemic and seasonal influenza and the 1918 pandemic specifically. Therefore, these estimates are deemed reasonable for the purposes of this study.

Concerns related to the third potential source of error, i.e. the reliability of descriptions of community life, were also minimized through consideration of multiple ethnographic and historical publications written by anthropologists and other academics, as well as by residents of the study community and nearby regions. As discussed in the previous chapter, models by nature are simplified versions of more complex systems and thus require restrictions to the levels of detail and heterogeneity that are included. Therefore, broad and typical patterns of behavior and activities frequently mentioned in the different sources were modeled in this research, despite known variation among different communities within Newfoundland, including the study community. Further, it must be stressed that this research does not aim to recreate what actually happened during the 1918 pandemic in the study community. Rather, detailed information is used to construct plausible scenarios that can test hypotheses about disease spread in communities that share similar characteristics, such as small size or traditional kinship organization around different types of economic activities. Consequently, some error or reasonable assumptions inconsistent with historical evidence, such as the inclusion of churches known to be absent in the study community itself but present in the immediate region and common in many other communities, are not only acceptable but perhaps even preferred, in order to make the model more generalizable.

Description of Models

Data collected for this research were used to construct two simulation models that are simplified representations of daily life and important relationships in small, traditional communities like Newell's Island. As mentioned above, the models were designed to be as similar to each other as possible in many features and processes to facilitate comparison of critical assumptions related to contact patterns among individuals. This section describes both models in more detail, beginning with a discussion of the construction of the model population used for the models. The structure of each model is then described separately to demonstrate how the different assumptions affect agent behavior and interactions and disease transmission processes. Then, the mortality and adoption processes are discussed; these processes are largely similar for both models, although some differences are highlighted. Finally, data output files and procedures, which are the same for both models, are described.

Family reconstitution and construction of model population

Although the models are not intended to faithfully reconstruct a specific community or reproduce its experience during the 1918 pandemic, a real community was chosen as the study community in order to make the demographic structure (e.g. household composition and the age and sex distribution) and activities of daily life as authentic as possible. Therefore, the construction of the model population involved two interrelated stages of data manipulation: the necessary first step of family reconstitution to identify known and plausible kin relationships among the residents of the study community, and subsequent translation of that information to a population of simulated individuals similar in characteristics to the study community.

Newell's Island was chosen as the study community for several reasons. First, the models used in these analyses are extensions of an earlier model designed for the community of St. Anthony, Newfoundland and Labrador, so another Newfoundland outport was desired in order to simplify modifications and enable future comparisons of different communities within a larger region. Additionally, records indicated that there were numerous cases and deaths during the pandemic in the immediate region. Further, the selection of the study community was based on a target size of approximately 100 residents; this target size increased the likelihood that sufficient information would be available, yet is small enough to allow the completion of family reconstitution in a manageable timeframe. The small size of Newell's Island combined with its proximity to Greenspond, a region with a rich historical record, proved ideal for this purpose. Accordingly, the model population is based on the individuals listed in the 1911 nominal census for Newell's Island, which included full names, sex, relationship of the individual to the head of the household, marital status, birth month and year, age, and birthplace for 114 people distributed into 23 dwellings. Additional information from the sources discussed near the beginning of this chapter, such as parish records and published interviews, further support the genealogical details provided by the census.

Whenever possible, multiple sources were used to link individuals and households together, especially when slight variations in dates or spelling of names occurred. Ultimately, family reconstitution was completed in two phases. The first phase focused on family relationships that were considered reliable from the preponderance of available data. In the second phase, reasonable assumptions were made to link together groups with the same surname into larger family trees. Typically, these assumptions either were based on references in various secondary sources to individuals with no corresponding records or involved choosing among a small number of possible individuals when records were insufficient to determine which one was the actual relative referenced in different sources. Decisions were reinforced by ages or dates of relevant life events; for example, potential parent-child relationships were assumed to be rational if the age difference between the two individuals fell within a biologically possible and culturally reasonable range for reproduction. These strategies resulted in a few large family trees that connected the majority of households in the census into an extended kinship network. The identified relationships were then used to assign characteristics to the agents in the model population.

Individuals in the model population were assigned parsimoniously to fishing crews according to crew formation strategies described in the ethnographic literature. Crewmates typically included fathers, sons, brothers, and cousins who were grouped together until target crew sizes of approximately 4-8 men were achieved; this target is supported by photographs, published recollections, and personal communication with other researchers. The model population is thus distributed into nine crews actually ranging in size from 4 to 6 men.

The members of each household were also assigned to one of two churches in the model. Church assignments were generally informed by archival records, such as baptism, marriage and burial records. In these records, religion of the individuals was explicitly listed or can be inferred from the name or affiliation of the person performing the rites. When such information was unavailable, individuals were generally assigned to the same churches as close family members in different dwellings.

The modeling of churches does not reflect the exact nature of historical reality, however. First, Newell’s Island did not have its own churches; residents instead traveled to Greenspond for services. Therefore, it may be more appropriate to consider the clergy in this model to be lay ministers or church elders. No individuals were listed in the Newell's Island census as clergy and available information did not reveal details on individuals filling lay or elder roles during the relevant time period. Therefore assignment of individuals to the clergy role was based on suitable criteria such as adult age and male sex. For example, a family with a large number of adult, unmarried sons was re-assigned to the relevant church and one of the sons given the role of pastor.

Further, records indicate that Newell's Island residents adhered to three major denominations (Church of England, United/Methodist and Salvation Army), but only churches for the first two denominations are considered in the models, partly because of the relatively small congregation size identified for the Salvation Army. Individuals whose records indicated probable membership in the Salvation Army were assigned to the other two churches along family lines if possible, as well as to maintain distributions proportional to those indicated for Newell's Island in the 1921 aggregate census (Colonial Secretary's Department, 1923).

While historical records indicated that clergymen in Greenspond were not teachers at the local schools, these roles were often combined in smaller outports, so this simplifying generalization was used in the models. The individual assigned to a teacher/clergyman role was identified as having worked as a teacher in the community at one point (Winsor, 1979). Winsor (1979) also listed the female teacher in Newell's Island around 1918. However, this individual was too young for such a role in the 1911 census, so a suitably aged female relative was assigned instead, resulting in two teachers for the school. In order to avoid three teachers for a relatively small school, the male designated as clergy for the second church, i.e. the son in the large family mentioned above, was assigned to an occupation of traveling clergy. This modeling decision was supported by historical sources, which suggest that Greenspond pastors were responsible for a broad circuit of surrounding communities and often traveled to conduct small services and rites or visit ill or homebound congregants (e.g. Winsor, 1982; Winsor, 1990).

In addition to fishermen, teachers and clergy, several other occupations or roles are considered in the models, corresponding to age- and sex-related activities such as school attendance and childcare (Table 6.1). Although there was a doctor in Greenspond who traveled as needed to surrounding communities including Newell's Island, many Newfoundland communities in the early 20th century did not have doctors or nurses. In order to make this model generalizable, medical personnel were excluded. The different occupation codes are briefly described in Table 6.1, while Figure 6.1 shows the frequency of each type of agent in the model population.

Because mortality is included in this model, it is necessary to consider what happens to dependent children if their primary caretakers die and new caretakers must be found. This replacement process, described further below, requires three additional occupation categories for men who take over childcare when there are no suitable female agents available. These men retain their original occupation code, as they continue to perform their regular activities if only older children are adopted or may return to previous occupations if dependent children die before the end of the simulated epidemic. However, these male agents are also designated with an additional occupation category that indicates their caretaking status and corresponds to their original occupation. These categories are teacher-caretakers and fishermen-caretakers, who adopt school-aged children only and do not change their behavior, and stay-at-home-dads, who adopt at least one preschool-aged child and, at least temporarily, stop fishing. No agents are initialized in these categories.

Table 6.1. Description of occupation codes assigned to model agents

Occupation Code[a]	Description
0	Mothers without preschool-aged children, but with at least some school-aged children between ages 5 and 10. Behave like type 2 agents during the week and type 7 agents on Saturday. No individuals are assigned this code initially, but it is needed in some cases of adoption.
1	Fishermen – includes most males older than 15.
2	Women older than 15 who have no or only older (>= 10 years) children and thus can participate in shore duties with some probability without adjusting behavior for childcare.
3	Female – teacher. Male – teacher/clergy.
4	Traveling clergy – assumed to be absent during the day Monday through Saturday, at home at night, behaves like a type 3 male agent on Sundays.
7	Mothers with at least one preschool-aged child requiring extensive care
8	School-aged children
9	Preschool-aged children. This code also may include daughters or other women in the household older than 15 years who assist with childcare in particularly large families. However, there are no such individuals in the Newell's Island model population.

[a] Female caretakers in households with children younger than 10 years are assigned to either type 0 or 7, and only one such agent is allowed per household. Multiple agents of type 2 or 9 are allowed in a single household.

Including the boat, church and occupation assignments, members of the population model have 12 total attributes that are read in via text files during initialization of the models. The other attributes are: ID number, residence (all agents are set to Newell's Island), disease status (all initialized as susceptible; the first case is chosen during initialization), dwelling and household (multiple households may live together in a dwelling), extended family (assigned according to surname of the household, i.e. married women are assigned to their husbands' extended family), sex, age, and health history. The residence and health history variables are not currently used and are intended for extensions of the model. For example, residence can be used in future versions that consider spread of the disease among multiple islands in the Greenspond region. Health history is used to indicate an agent's relative health status and mediates outcomes when the agent faces a potential disease-transmitting contact. Appendix A lists the model population and their assigned values for each attribute.

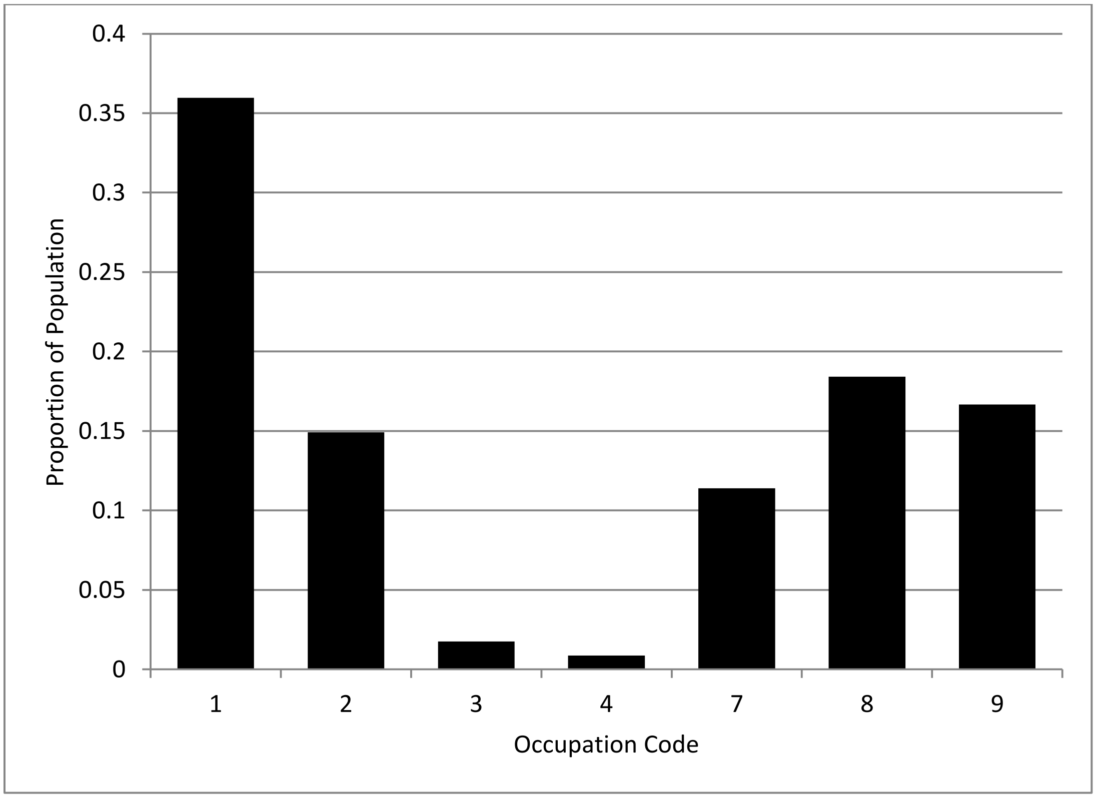


Figure 6.1. Occupation distribution of the model population

Structure of the agent-based (dynamic network) model

As mentioned above, the agent-based model (ABM) used in this research is based on a version previously designed to study similar issues for St. Anthony, Newfoundland and Labrador (see, for example, Orbann et al., 2014 and Dimka et al., in press). The St. Anthony model was written in Repast Simphony, a modeling platform based on the Java programming language, and was later translated to another platform, Netlogo, retaining the assumptions and design features as much as possible during the translation. The Netlogo version was further modified by the author for this project to make the community structure, activity of agents and other details more consistent with the study community of Newell's Island. Complete code for this model is provided in Appendix B.

The model is visualized as buildings organized onto a grid in rectangular or square units of varying sizes, representing 23 dwellings, a school, two churches, and nine boats (Figure 6.2). Because specific locations of dwellings and other locations on Newell's Island are not available from archival sources and because research goals emphasize transmission within important social spaces rather than transmission due to encounters while traveling between such spaces, the positions of the buildings do not reflect geographical reality. The sizes of the respective building types are chosen to approximate reasonable densities based on estimated sizes of such buildings in the community and their typical occupancies. Appendix A also includes the read-in file that lists each building's location on the grid, dimensions and type.

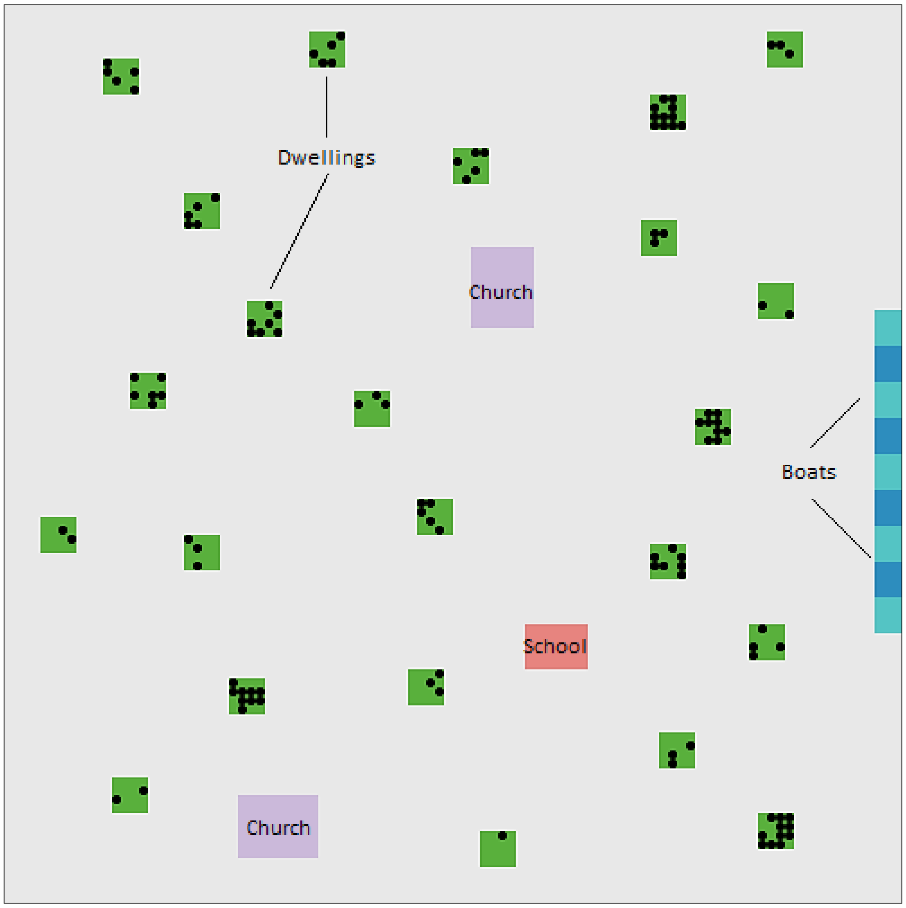


Figure 6.2. Visualization of the agent-based model at initialization indicating the different types of buildings. All agents (black circles) begin a simulation in their assigned dwellings.

Each cell of a modeled building can only be occupied by a single agent. Agents are represented by small circles that initialize as black and subsequently change color to reflect the individual's disease status throughout a simulated epidemic. During each time step of a simulation, an agent chooses a desired destination based on general rules of behaviors, disappears from its current location, and reappears in the new location; behavioral rules and typical destinations for different types of agents are described in more detail below. Figure 6.3 presents a schema of the major steps each agent follows during each time step of a simulation.

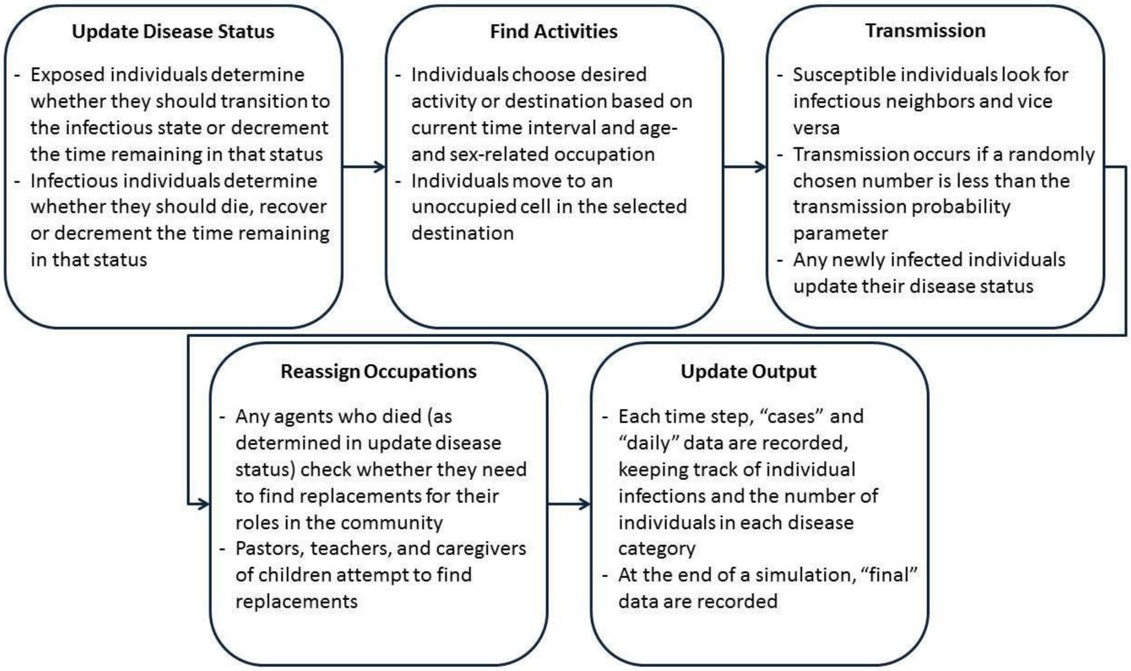


Figure 6.3. Schema of the agent-based model indicating major procedures performed each tick of a simulation.

The model proceeds in time steps of four-hour blocks for 400 steps (approximately 67 days), a value chosen to allow completion of epidemics for most sets of parameter values. During four of the six daily time steps, agents move in some way; the remaining two are nighttime so agents remain stationary while they "sleep." With each time step, each agent (in a random order each step) updates its disease status, moves to a new location either within the same building or in a different building depending on the time of day and the agent's sex- and age-related occupation, checks for susceptible or infectious neighbors depending on its own disease status, and transmits or becomes infected by the pathogen if certain requirements are met.

Table 6.2 provides an overview of the different activities engaged in by various types of agents Monday through Saturday. The same schedule of activities is followed for all agents of a particular category. Slight variations to the Saturday schedules are possible, particularly for children or other individuals who occasionally move as part of a group determined by caretakers, as the membership of these traveling groups depends in part on the sequence of agents called during a particular time step. On Sundays, all agents behave the same. Families move together to desired locations, but are not necessarily neighbors within those locations (e.g. a mechanism to allow families to sit together in the church has not been added to the model at the present time). In the first daytime interval, all members of the community attend their assigned church, before returning home during the second time step. In the third time step, each family may choose to visit another dwelling or remain at home with some probability.

Disease transmission can occur within any location, but only between agents who form a susceptible-infectious pair, are in the same building or in adjacent boats, and are von Neumann neighbors, i.e. one agent is in the cell to the north, south, west or east of the other agent. Currently, the disease parameters (transmission probability, length of latent period, length of infectious period, and mortality probability) are established at initialization of a simulation, are constant values, and are the same for all agents. During the transmission process, an infectious agent determines whether it has any von Neumann neighbors who are susceptible. If so, a random number is selected and compared to the transmission probability. If the random number is less than the transmission probability, transmission occurs and the newly infected agent enters the latent period. An analogous process occurs when susceptible agents search for infectious neighbors.

Table 6.2. Daily activity schedule (Monday – Saturday) for all occupations

Occupation Code	Mon-Fri 6am-10am	Mon-Fri 10am-2pm[b]	Mon-Fri 2pm-6pm[b]	Sat 6am-10am[b]	Sat 10am-2pm[b]	Sat 2pm-6pm[a, b]
0	Home	.8 Boat, .04 Visit, .16 Home	.8 Boat, .2 Home	Home	.5 Visit with group, .5 Home	Home
1	Boat	Boat	Boat	Boat	Boat	Boat
2	Home	.8 Boat, .04 Visit, .16 Home	.8 Boat, .2 Home	Home	.8 Boat, .04 Visit, .16 Home	.8 Boat, .2 Home
3	School	School	School	Home	.5 Visit, .5 Home	Home
4[c]	Travel	Travel	Travel	Travel	Travel	Travel
7	Home	.5 Visit with group, .5 Home	Home	Home	.5 Visit with group, .5 Home	Home
8 (>= 10 yrs)	School	School	School	.8 Boat, .2 Home	.8 Boat, .16 School, .04 Home	.8 Boat, .2 Home
8 (< 10 yrs)	School	School	School	Home	.8 School, .1 Visit with group, .1 Home	Home
9	Home	.5 Visit with group, .5 Home	Home	Home	.5 Visit with group, .5 Home	Home
Fisherman-caretaker	Boat	Boat	Boat	Boat	Boat	Boat
Stay-at-Home Dad	Home	Home	Home	Home	Home	Home
Teacher-caretaker	School	School	School	Home	.5 Visit, .5 Home	Home

[a] In the evening time intervals every day (6pm-10pm), all agents return home. During the following two time intervals (10pm-2am and 2am-6am) they do not move from the cells they choose upon their initial return.

[b] The proportions indicate the probability the associated activity/destination is chosen, on average.

[c] Occupation 4 agents are assumed to travel outside of the community each day and so move to the lower right cell of the map to indicate absence; because there is only one agent currently assigned to this category, no disease transmission occurs.

Structure of the (static) social network model

The social network (SN) model was written in Netlogo, and is visualized as circular nodes connected by links representing social relationships (Figure 6.4). The model visualization approximates a layout where nodes connected to each other are placed closer together than unconnected nodes. The model follows the same time schedule as the dynamic, agent-based model, with time steps representing four-hour intervals. Complete code for this model is also provided in Appendix B, and Figure 6.5 presents the major steps each node follows during each time step of a simulation.

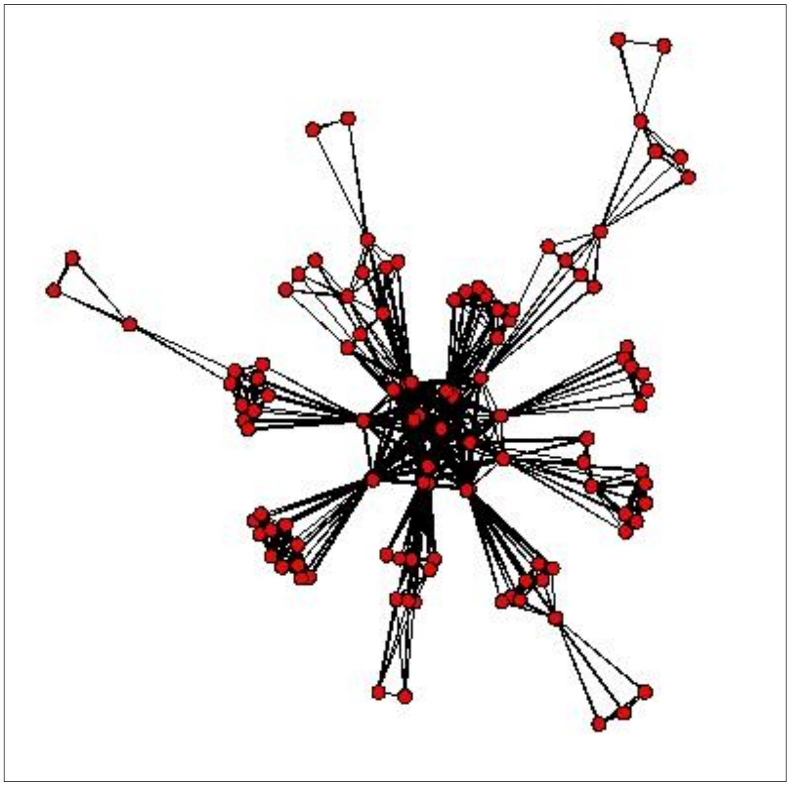
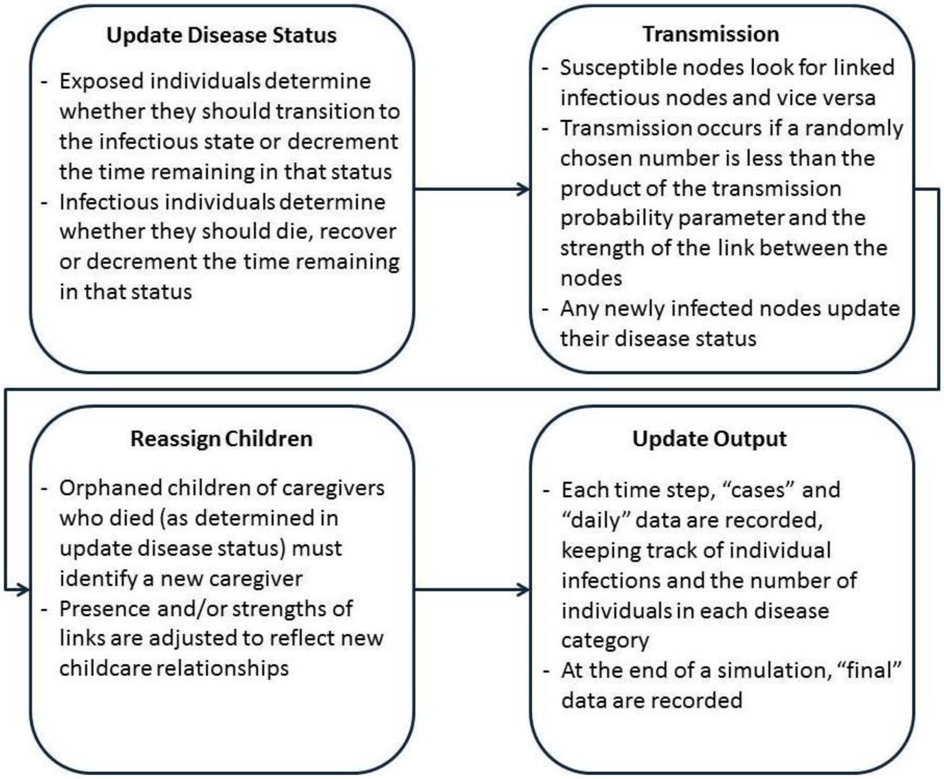


Figure 6.4. Visualization of the social network model. In this image, the central cluster represents schoolchildren and the branches represent adults, typically members of the same dwelling. Adults in different dwellings who fish together are also linked. Links among church members are not represented in the image because the large number of these relatively weak links overwhelms the details of the stronger links based on more regular or daily interactions.



Update Disease Status

- Exposed individuals determine whether they should transition to the infectious state or decrement the time remaining in that status
- Infectious individuals determine whether they should die, recover or decrement the time remaining in that status

Transmission

- Susceptible nodes look for linked infectious nodes and vice versa
- Transmission occurs if a randomly chosen number is less than the product of the transmission probability parameter and the strength of the link between the nodes
- Any newly infected nodes update their disease status

Reassign Children

- Orphaned children of caregivers who died (as determined in update disease status) must identify a new caregiver
- Presence and/or strengths of links are adjusted to reflect new childcare relationships

Update Output

- Each time step, “cases” and “daily” data are recorded, keeping track of individual infections and the number of individuals in each disease category
- At the end of a simulation, “final” data are recorded

Figure 6.5. Schema of the social network model indicating major procedures performed each tick of a simulation

Because movement is not incorporated into this model, the relative likelihood of transmission each time step from an infectious node to a susceptible one is instead modified by the strength of the link between the pair. Strengths are calculated by first determining the number of time steps in the agent-based model (ABM) that the two individuals might come into contact with each other in specific building types, on average, during a week of modeled time. This sum is divided by the possible number of time steps (42) and multiplied by a scaling factor related to the size of the building type in question. The scaling factors aim to reflect the amount of time two agents in the same building type might be von Neumann neighbors. For example, a dwelling is 4x4 cells. Since the four corner cells have two von Neumann neighbors, the eight side cells have three neighbors, and the internal four cells have four neighbors, the “average” dwelling cell has three von Neumann neighbors. If the first member of a susceptible-infectious pair chooses this “average” cell, the other member has a 3/15 chance of selecting one of the neighboring cells out of the remaining available cells. Therefore, the scaling factor for interactions in a dwelling is 0.2.

The values for all potential interactions within various building types between two nodes with specific occupations are then added to give an overall strength for the interaction between these two types of nodes. For example, a schoolchild (occupation code 8) and a fisherman (occupation code 1) living in the same household and fishing in the same boat are in a dwelling together for one evening and two nighttime steps each day, plus two daytime steps on Sundays (23 time steps total, or about 55% of the week), giving a strength of about 0.1095 when multiplied by the dwelling scaling factor. If the schoolchild is 10 years or older, it chooses to fish during the three daytime steps of Saturday with a probability of 0.8 each time step. Since fishermen always fish on Saturdays, the pair fish together, on average, 2.4 time steps, producing a strength of about 0.0147 when this proportion is multiplied by the scaling factor for boats. The different strength components for a particular pair are added to determine a total strength; in the example described here, the cumulative rounded strength is 0.124. A similar process is used to calculate baseline strengths for every type of node pair based on occupation, dwelling, household, and boat assignments. Strength calculations and values for different types of node pairs are provided in Appendix C; the exact strengths read in for all pairs of individuals in the model population are included in Appendix A.

The strength component for church attendance is determined using the same procedure but is not included in the strengths listed in the read-in files. Rather, it is added within the model code upon initialization to enable easy substitution of this value if, for example, the degree of church attendance is changed in future versions of the model. Strength components for visiting among households currently are not calculated and do not contribute to overall strengths of links. In the ABM, visiting destinations are chosen randomly among households with residents at home (a pool which varies depending on the sequence of agents called, the available spots in the house and the size of the traveling group, and the alternative behaviors agents may choose) and visiting only occurs during a few time steps of a modeled week. This relatively small probability distributed across all potential destination households results in a very small strength value and thus is assumed too weak to contribute to transmission in the network compared to more frequent, repetitive contacts.

Finally, to reflect interactions that may occur between shore crews or even between fishers in boats, crew members assigned to boats that are adjacent to each other in the ABM, identified by sequential building ID numbers, add a small component of strength. As with other building types, the locations of boats/shore crews do not reflect geographic reality, but there is an assumption that in reality adjacent boats/shore crews would be physically situated next to each other and/or represent boats of relatives or friends who would tend to fish together. This strength component is calculated by taking the proportion of time steps per week that both members of the pair choose to fish at the same time multiplied by a scaling factor determined by the size of boundaries between boats. This scaling factors accounts for the fact that two individuals assigned to different crews may be von Neumann neighbors in the ABM and thus capable of transmitting disease only if they both choose to occupy adjacent cells along this boundary.

The strengths of the links between nodes are constant or static during the course of a simulation, except when nodes representing children younger than 15 years old need to be adopted by a new primary caretaker. In these instances, the strengths of all links belonging to both the children and the new caretakers may need to change, depending on whether the caretaker changes occupations and/or the children move to new households. The mortality and adoption processes for both models are discussed in more detail below.

As mentioned above, the strengths of the links mediate whether transmission occurs between a susceptible-infectious pair of linked nodes. Similar to the ABM, each susceptible node looks for any linked infectious nodes each time step, and vice versa, and a random number is chosen to determine if transmission should occur. However, the transmission probability parameter is first multiplied by the strength of the link between the two nodes before it is compared to the random number, to account for the relative weight of the relationship between the two nodes.

Mortality and adoption processes

In the models, mortality can only occur when an agent’s disease status is infectious, with the probability of dying equal across all time steps of the infectious period. As with transmission procedures, a randomly selected number is compared to the mortality probability parameter, which is established at initialization. Upon death, an agent (or node) records its time and place of death. In the ABM, agents create a copy of themselves at the location in which they died; this copy is typically hidden but may be revealed to illustrate patterns related to place of death. The original copy moves to the bottom left of the visualization, which represents the “cemetery”. In the SN model, the deceased node and each of its links are removed from the model.

In both models, any individuals who died during each time step must determine whether they need to find a survivor in the community to take over their occupation. For example, in the ABM, pastors and teachers identify replacements for these roles. The ABM pastor/teacher replacement procedure simply identifies the surviving agents who are old enough, members of the appropriate sex, and are not assigned to other important occupations such as primary caretakers of preschool-aged children. One of these agents is randomly selected, and its relevant occupation variables and thus its subsequent behaviors are changed. The sexes of the teachers are kept consistent, i.e. the male teacher/clergy only selects from males while the female teacher only selects from females. If there are no surviving agents fitting the necessary criteria, no further reassignments occur. The resident pastor (occupation code 3) restricts possible replacements to fisherman older than 30 years of age under the assumption that a more mature, established individual would play such a guiding role in the community. The traveling clergy (occupation code 4) allows replacements 25 years and older to reflect the likelihood that, at least in a more general model community, an individual in this role may be new to the profession or a missionary and thus potentially younger.

Replacements for female teachers must be out of school, i.e. older than 15 years old. Replacement of these few occupations does not currently occur in the SN model, as the procedures are computationally expensive and such replacement is inconsistent with the aim of keeping the network as static as possible.

In both models, new caretakers of children must be designated upon the death of the previous caretaker. This scenario is the only time nodes and links change in the SN model. The code structure of the adoption procedures differs in the two models, though the same general rules are followed. If the primary caretaker (i.e. an individual assigned to occupation type 0, 2, or 7, a fisherman-caretaker, a teacher-caretaker, or a stay-at-home-dad, depending on the ages of the surviving children and sex of the caretaker) dies while at least one child survives, then the caretaker in the ABM, or one of the children in the SN model, identifies a new caretaker according to a preferred order. First, the individual would choose from members of the same household, then members of the same dwelling but a different household, then members of a different dwelling belonging to the same extended family, then any surviving adults in the community. Within each of these categories, the individual also ranks potential caretakers by occupation code, so a woman already engaged in childcare (a 0 or 7 depending on the ages of children already in her care) would be chosen before a 2 or an older 9, who would be chosen before a male caretaker. When considering the pool of male caretakers, the individual similarly checks first to see if there is already a male caretaker in the potential caretaker's household. This test prevents, for example, two different fishermen each adopting children. Because it is unlikely that individuals holding clerical roles in the community would relinquish them for caretaking responsibilities under other circumstances, teachers/clergy in occupation code 3 are only allowed to adopt children who are school-aged and who live in the same dwelling as them, and traveling clergy in occupation code 4 are not allowed to adopt at all. Female teachers are not allowed to adopt because in Newfoundland communities, these women were frequently, though not always, boarders with no relation to the others in the household. Male teachers, on the other hand, were more often the heads of their household, fathers or relatives of the children living there, and established members of the community.

These models assume that adopted children move into the new caretaker's household. Once the new caretaker has been selected, reassignment frequently requires agents to change occupation-related and other variables, in order to modify behavior accordingly throughout the rest of the simulation. Table 6.3 indicates which occupations of new caretakers are changed in different scenarios. If necessary, the newly adopted children change their dwelling, household, church and boat values to reflect their new residence and ensure their behavior changes accordingly. However, their original extended family variable value is retained.

To account for these behavioral changes in the SN model, relevant nodes increment or decrement their link strengths with connected nodes. For example, a woman previously assigned to an occupation of 0 who adopts preschool-aged children needs to become a 7. This transformation results in decreasing the strengths of links representing fishing relationships, and increasing the strengths of links to nodes in the same dwelling and household by values reflecting a larger proportion of time spent at home. Children change link strengths to account for new or modified residence, boat or church relationships. Both caretaker and children nodes change their link strengths, as needed, if the differences are larger than an arbitrary threshold of 0.001.

Table 6.3. Reassignment strategy for agents adopting children

Agents in occupation code:	adopting children from agents assigned to:	become or retain the occupation status of:
0	Fisherman-caretaker, Teacher-caretaker, 0 or 2	0
0	Stay-at-home-dad or 7	7
1	Fisherman-caretaker, Teacher-caretaker, 0 or 2	Fisherman-caretaker
1	Stay-at-home-dad or 7	Stay-at-home-dad
2	Fisherman-caretaker, Teacher-caretaker, 0	0
2	2	2
2	Stay-at-home-dad or 7	7
3	Fisherman-caretaker, Teacher-caretaker, 0 or 2	Teacher-caretaker
7	Any type of caretaker	7
9s over age 15	Would only be selected to replace 7s in their household; in any other scenario, that 7 would be the preferred choice	7
Fisherman-caretaker	Fisherman-caretaker, Teacher-caretaker, 0 or 2	Fisherman-caretaker
Fisherman-caretaker	Stay-at-home-dad or 7	Stay-at-home-dad
Stay-at-home-dad	Any type of caretaker	Stay-at-home-dad
Teacher-caretaker	Fisherman-caretaker, Teacher-caretaker, 0 or 2	Teacher-caretaker

If there are no suitable caretakers available, the children will be adopted “out” of the community. In the ABM, the agents simply move to the upper right corner of the visualization and do not interact further with other agents. In the SN model, the nodes and all their links are removed. In both models, orphans record the time they leave and their disease status. Infections among orphans that occur before they leave are considered in data analyses as these cases do reflect the overall epidemic experience of the model community. However, orphans do not continue to update their disease status after they are adopted out of the community and so any potential deaths among these children are not included in the mortality tally. It is unlikely such deaths would be recorded in archival records associated with the former community so any comparisons of model output to observed data would be unrealistic if these deaths were included.

Finally, if a non-orphaned child dies in either model, it will check to see if it has any surviving siblings at all, as well as any surviving siblings under the age of 5 years old, and if its primary caretaker is male. If these tests indicate no dependent children require continued care, the male caretakers reset relevant occupation variables – and in the SN model, link strengths, as needed – and return to any previous activities that may have stopped. For example, a stay-at-home-dad will begin fishing again and become either a regular fisherman (no surviving children) or a fisherman-caretaker (no children under 5 remaining). It is assumed that females will remain in their occupation status even after all children have died, rather than return to any previous occupation-related behaviors. This modeling choice, which also spares the computational expense of making additional changes, is based on the assumption that after a household disruption from death, a woman returning to other work, e.g. fishing activities, would be less critical or likely to occur, at least within the short duration of a simulated epidemic.

Data output

During the course of simulations, output data is exported into three comma-delimited files. For each file, run numbers, disease-related parameters (e.g. the value of the transmission probability), and attributes of the first case are always recorded. The "Cases" file also records, for all individuals in the model population, the place and time the individual was infected (the default value of -1 is recorded if the individual escaped the simulated epidemic), and if applicable, the place and time it died or time it was adopted out of the community. The "Daily" file records the number of individuals in each disease status and the number of orphans adopted out of the community each time step of the simulation. The "Final" file records the total number of individuals in each disease status, the total number of individuals ever infected, and a count to verify all members of the model community were either susceptible or removed (recovered, dead or adopted out). This last count provides an easy way to determine that a simulated epidemic finished in the allotted time; in that case, the count will equal the total population size. Further, the total number of orphans and the total number of non-susceptible orphans are recorded to ensure that children who leave the community are counted as part of the epidemic.

Validation and Verification of the Models

Before addressing the research questions, the models needed to be verified and validated. These processes aimed to confirm the models work as planned and expected, including through debugging errors in code, and that they produce results consistent with observed data from real-world epidemics. Both models were evaluated using the same procedures. First, simulations were observed and evaluated to determine whether the models behave in realistic ways, producing outcomes that match general observations in literature and actual epidemics. These outcomes include standard epidemic curves, where the number of cases builds slowly to one or more peaks and then declines as the pool of susceptible individuals becomes depleted, as well as stochastic instances where epidemics fail to take off even when parameters are chosen to maximize the chance of an epidemic.

In addition to looking for these expected outcomes, model behaviors were also evaluated to see how outcomes change with different parameter settings. These sensitivity analyses involved varying each parameter of interest across an extreme range of values while the other parameters were held constant. Table 6.4 indicates which variables were included in these analyses and the values used for each variable; results of these analyses are discussed in the following chapter. The constant latent and infectious period values were chosen after assessing different values for these parameters as given in the literature (e.g. Ferguson et al., 2004; Mills et al., 2004). The constant value for the transmission probability was chosen via preliminary sensitivity analyses and is the average of the values for each model which produce an attack rate of about 30%, corresponding to observed data for the larger Greenspond region (at least 449 cases out of an estimated 1500 people). The constant mortality probability was estimated from mortality data in the Greenspond region and derived by setting the desired total survival probability equal to [(1- the probability of death per time step) raised to a power corresponding to the number of time steps that an agent is at risk of dying]. This quantity gives the overall probability of not dying throughout the infectious period, so it is subtracted from 1 and set equal to the desired case fatality rate. Solving the equation gives the probability of dying per time step. Mortality for Greenspond during the 1918 flu was about 7.3 deaths per 1000, which converts to a case fatality rate of about 24 deaths per 1000 using a 30% attack rate. Using an infectious period of 18 ticks or 3 days gives the equation:

$$1 - (1 - \text{probability of death})^{18} = 0.024$$

The solution to this equation gives the mortality probability of 0.0013 per tick indicated in Table 6.4.

Table 6.4. Values of parameters used in sensitivity analyses

Parameter	Value when held constant	Range of values when varied
Transmission probability	0.055	0.01-0.1 in increments of 0.01, 0.3, 0.6, 0.9, 1.0
Length of latent period	6 ticks (1 day)	6-30 ticks (1-5 days)
Length of infectious period	18 ticks (3 days)	6-60 ticks (1-10 days)
Mortality probability	0.0013	0.00005, 0.00025, 0.0005, .001, 0.01, 0.05, 0.1, 0.3, 0.6, 0.9, 1.0

Finally, the consistency of model output was tested via a repetition study. In this analysis, 20 sets of 1000 simulations each were completed. The average number of infectious individuals at each time step was calculated for each of these sets, and all sets were compared to each other. While randomness was both expected and desired, the models were deemed consistent if the majority of sets exhibited the same general shape as the curve produced by the grand mean with no major outliers. This process was also used to determine how many simulations were necessary to perform when testing research hypotheses, in order to ensure a random set of runs would produce average values that reflect genuine underlying patterns. To determine how many runs were required, the number of simulations per set was reduced until a minimum number that still maintained consistency was identified. The repetition study indicated that 500 runs for each model were sufficient.

Methods for Addressing Research Questions

As discussed in Chapter 1 and at the beginning of this chapter, this project ultimately addressed two research objectives. First, the two models were compared to evaluate whether and how different assumptions about model structure and individual behaviors and relationships affect model outcomes. This comparison was based primarily on the sensitivity analyses described above. Outcomes were derived from manipulation and exploration of the data recorded in the output files for each model. Final and daily data files were used to calculate typical epidemic measures including average final proportion, average peak proportion, average peak day and average day the last infected case recovered, died or left the community. Generally, comparisons between the two models were based on qualitative trends across values for different parameters of interest, as broad patterns were considered most important for understanding model behaviors. However, in some cases, statistical analyses were performed to evaluate whether the differences observed between means for the measures listed above were due to chance or statistically significant. When comparing between the two models, two sample t-tests were conducted, assuming unequal variances (to be conservative) and because substantially large differences in variances were observed for at least some of the measures. A few comparisons also aimed to analyze differences in means across three or more values of a particular parameter for a single model; in these cases, analysis of variance (ANOVA) tests were performed. All analyses were conducted using data analysis functions in Microsoft Excel and an alpha level of 0.05. The results for these analyses are presented in the following chapter.

The second research objective focused on the influence of different age- and sex-related activities and relationships on the spread of infectious disease epidemics. The occupation categories were combined into four larger groups of fishermen (occupation 1), fisherwomen (occupations 0 and 2), “at-home” individuals (occupations 7 and 9), and schoolchildren (occupation 8, all ages). These larger groups were chosen to reflect similar activities or roles in the community while minimizing “noise” that might be introduced from slight differences in the frequency of specific activities. Teachers and clergy (occupations 3 and 4) were not considered in these analyses because of the relative scarcity in the community, as well as how their activities are modeled. Teachers and resident clergy follow very similar activity patterns to younger schoolchildren, while travelling clergy are absent from the community during virtually all daytime steps and so are expected to contribute to transmission only within their own dwellings and during church services.

The roles of the four subgroups on disease transmission in the population were investigated by evaluating the impact of the category of the first case. Five hundred simulations were run for each scenario, and data output files were analyzed in three different ways. First, epidemic outcomes, i.e. final proportion, peak proportion, peak day and last day, were calculated. Second, occupation-specific outcomes were compared across different groups holding the category of the first case constant. The outcomes considered for these analyses included the total proportion of individuals affected in each group and the average time of infection for each group. Finally, analyses compared how these occupation-specific outcomes vary within each group as the category of the first case varied. For all comparisons, ANOVA analyses were first conducted to determine whether there was a significant difference in means across the four groups, again using an alpha level of 0.05. If a difference was observed, ad hoc two sample t-tests were conducted to determine which pairwise comparisons contributed to the overall difference. The results for these analyses are presented in Chapter 8.

CHAPTER 7 – SENSITIVITY ANALYSES RESULTS AND DISCUSSION

One of the major goals of this project was to investigate how structural or design assumptions related to the nature of contact networks affect model behavior and, by extension, general understanding of systems of disease transmission and the validity of any recommendations for interventions based on specific model types. As mentioned in the previous chapter, a common way to thoroughly evaluate model behavior is through sensitivity analyses that consider outcomes such as epidemic size and timing under different conditions or scenarios. These analyses are typically performed by varying one or more parameters across a range of values while holding other parameters constant. Consequently, simulation results demonstrate broad patterns in outcomes somewhat independent of particular parameter values estimated for the disease of interest. These broad patterns indicate both typical or average results as well as the possible range of variation produced by the model. Additionally, results can be used to determine the relative impact of individual parameters and possibly the relationship between parameters.

In the analyses here, the disease-related parameters (transmission probability, duration of latent and infectious periods, and mortality probability) are varied singly. Five hundred simulations were run for each set of parameter values, with subsequent analyses performed only on the simulations that qualified as an epidemic, arbitrarily defined as more than five percent of the population ever infected. Output from both the agent-based model (ABM) and social network (SN) model allows for calculation of average final size or total proportion ever infected, average proportion of infectious agents at the peak of an epidemic, average peak day of an epidemic, and average last day any agent is infectious. These measures were chosen because size and timing outcomes are typically of most interest for researchers, particularly those who use models to recommend public health policy and practice. Additionally, these outcomes are important for understanding model behavior because of how they influence each other. For example, if final size remains constant while the average day of last infection shifts later in an epidemic, the average peak proportion must become smaller. Therefore, the values for these different measures provide relatively simple ways of visualizing the probable shape of an entire epidemic curve.

In this chapter, the results of these analyses are presented for each parameter, with an emphasis on comparing the two models to each other. Because the goal is to understand broad patterns and trends, comparisons typically focus on qualitative differences between the two models. However, as discussed in the previous chapter, results of statistical analyses are occasionally reported to support interpretations of whether differences between the two models are meaningful. Further, for all parameters, the results for peak day and last day of an epidemic were qualitatively very similar, and so, in the interest of space, the last day results are typically not shown or discussed, unless unique characteristics are observed. After the sensitivity analyses are discussed, results for simulations that employ the parameter values estimated to produce outcomes appropriate for the 1918 influenza pandemic are presented. This chapter concludes with a discussion of implications for designing and interpreting outcomes for models incorporating different network structure assumptions.

Transmission Probability

The transmission probability was varied between 0.01 and 1.0 to capture the differences in model outcomes across an extreme range of values. These values included 0.01 to 0.1 in increments of 0.01, 0.3, 0.6, 0.9, and 1.0. A higher density of values were selected from the 0.01-0.1 range because analyses of the St. Anthony model upon which these models were based indicated that effects of the transmission probability change the most at smaller values. Interpretation of results at higher values must take into consideration the lack of data points, but general patterns can be extrapolated relatively easily.

The final size, or total proportion ever infected, follows similar patterns for both the ABM and SN models. Generally, this measure is approximately ten percent for both models at low transmission probabilities and increases rapidly in a somewhat logistic fashion until nearly 100% of the population is infected somewhere between transmission probabilities of 0.1 and 0.3 (Figure 7.1). The qualitative pattern of the results are easily explained; as the transmission probability increases, the likelihood that the disease will spread to more people, as long as contacts continue to occur during the course of an epidemic, also increases. However, since the population is closed, i.e. no new individuals are added, a limit is reached as the proportion infected approaches 1.

As Figure 7.1 indicates, the ABM produces slightly smaller epidemics at the two lowest transmission probabilities, possibly due to chance as there is no significant difference between the two models at transmission probabilities of either 0.01 (t = -1.96, df = 13, p = 0.07) or 0.02 (t = -1.32, df = 58, p = 0.19). However, the proportion infected in the ABM increases at a faster rate than in the SN model and remains larger throughout all other transmission probabilities. These differences are likely due to how contact networks are considered in the two models. As previously discussed, the ABM produces a dynamic contact network; although movement to particular social spaces is constrained by age- and sex-related behaviors, novel pairs of agents may come into contact within those spaces throughout the course of a simulation, allowing for continued transmission. In the SN model, however, potential contacts (linked nodes) are determined upon initialization and generally do not change, restricting the possibilities for transmission. As argued in other research using network models (e.g. Eames, 2008; Fefferman and Ng, 2007; Rahmandad and Sterman, 2008), the disease has the potential to become "trapped" within subgroups in the network, spreading to all members of the subgroup but unable to escape to the larger whole, resulting in an overall smaller final size.

Peak proportion results follow similar patterns, although the overall rate of increase and the difference between the two models is less marked. Further, the peak proportion values never appear to reach a plateau even at the highest transmission probabilities (Figure 7.2). Unlike in measures of final size, however, the SN model begins to produce larger peak proportions than the ABM somewhere between transmission probabilities of 0.6 and 0.9. The peak proportions for the two models are significantly different at transmission probabilities of 0.6 and 1.0 (t = 3.75, df = 763, p < 0.05; t = -

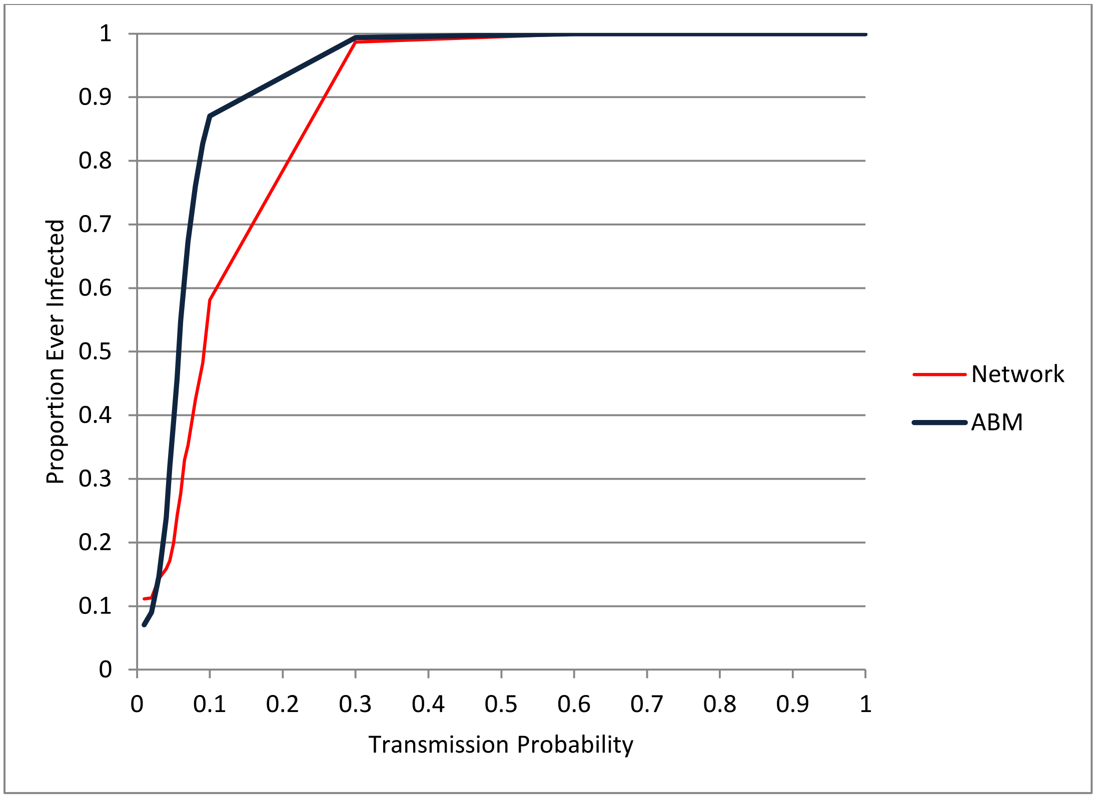


Figure 7.1. Final size of epidemics as the transmission probability is varied

3.95, df = 919, p < 0.05), but not at 0.9 (t = -1.73, df = 912, p = 0.08), suggesting higher transmission probabilities do have an actual effect on peak proportion in different model designs. However, the absolute differences between these outcomes are fewer than three infectious agents, so there is little practical concern, at least in small populations like the study community.

Peak day (Figure 7.3) and last day (results not shown) both follow similar patterns, with both models having earlier peak days at the lowest transmission probabilities before rising to a maximum near a probability of 0.1, and then decreasing to somewhat stable values at the highest transmission probabilities. Note that the ABM

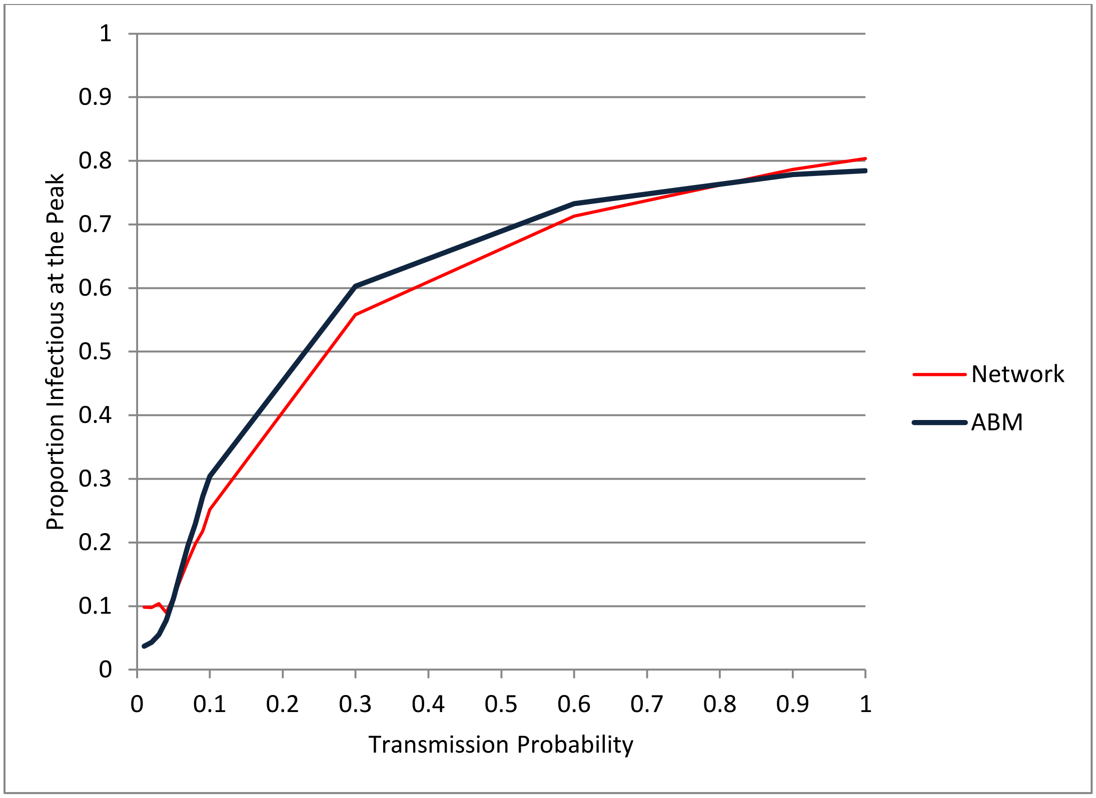


Figure 7.2. Proportion infectious at the peak as the transmission probability is varied

has a slight “hook” at the lowest probability values, likely due to chance (0.01 vs. 0.02: t = 0.92, df = 16, p = 0.37) and related to the small number of epidemics at 0.01 (N = 13 of 500 runs); this hook is not apparent in the last day data. The maximum peak day observed in both models is likely an effect of epidemic size. At low transmission probabilities, epidemics are smaller, as seen in the final size graph above, and so they end earlier since fewer individuals must proceed through the disease process. Even though epidemic size increases, the rate of spread at intermediate yet still fairly small transmission probabilities is slower, resulting in later peak days. By the highest transmission probabilities, the disease spreads rapidly even when epidemics are very large, with the result that epidemics actually peak and end earlier than those seen with more moderate transmission probabilities. Explanations for the differences between the two models across the range of values, such as the slightly later peak days for the SN model at moderate values, might be due to the static nature of the SN model; the potential of epidemics becoming "trapped" in subgroups can also affect the speed of outbreaks. However, this explanation does not account for the later peak days observed in the ABM model at extreme values of the transmission probability or at the maximum point of the curve.

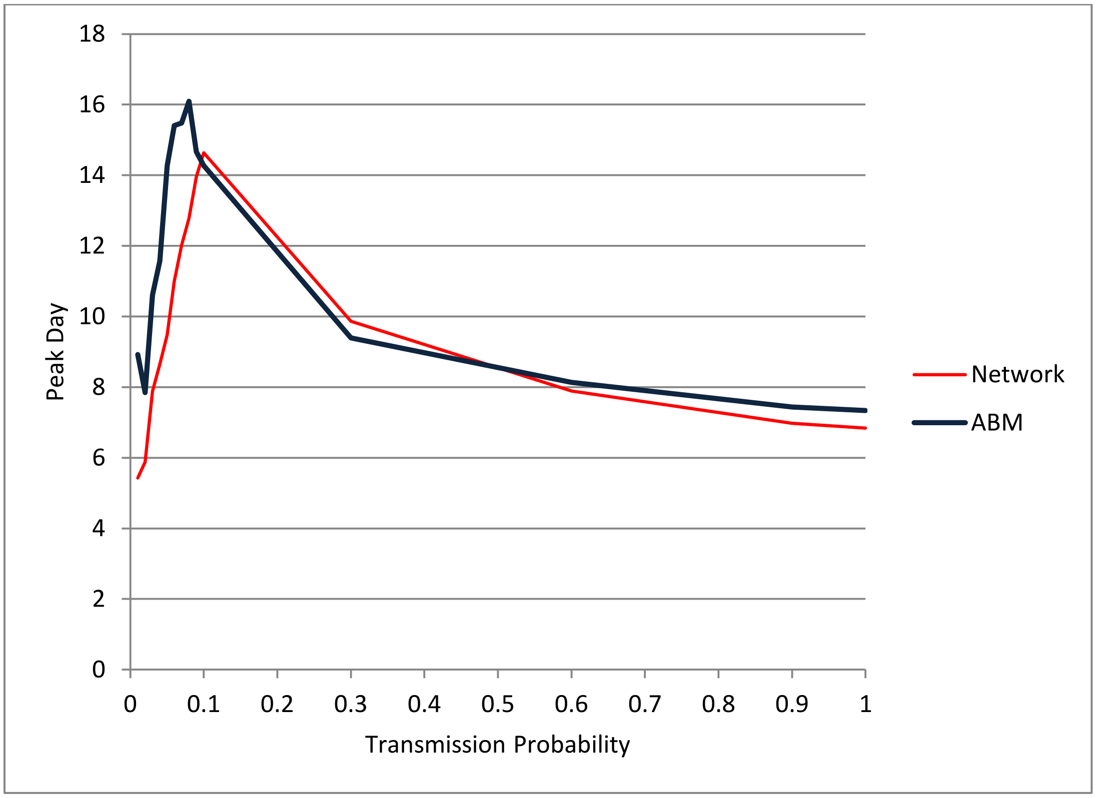


Figure 7.3. Peak day as the transmission probability is varied

Latent Period

The latent period was varied from 1 to 5 days (6 to 30 ticks). Results for these values indicate very little effect of the duration of this period on final size of epidemics

(Figure 7.4). Each model produces final sizes that vary within a range of about ten percent (approximately 11 individuals) across all values of the parameter. However, the ABM consistently produces epidemics that are larger by about 20% than the SN model, again likely due to the dynamic vs. static nature of contacts. Further, while the SN model proportion increases steadily for longer latent periods, the ABM fluctuates in size and direction of change at 3 and 4 days. There are no significant differences among final sizes for the different latent period durations in the SN model (F = 2.14, $p = 0.07$, df = 4, 1174). In the ABM, there is a significant difference among the average final sizes (F = 2.56, $p < 0.05$, df = 4, 1493), with subsequent pairwise t-tests indicating these differences are driven by the observed fluctuation at a latent period of 3 days (i.e. differences are significant at 1 vs. 3 and 3 vs. 4 days). The fluctuation at this duration may be due to the impact of Sunday behavior (church and increased visitation) when it occurs on the exact day the second generation of cases becomes infectious. Because contacts are weighted and static in the SN model, such periodic behavior would be expected to have less of an effect on epidemic outcomes.

Peak proportion also shows relatively little variation across different values of the latent period for both models (Figure 7.5). However, qualitatively, the peak proportion pattern differs from the final proportion in two noticeable ways. First, both models decline slightly into an approximate plateau as the latent period increases. Although there is a slight increase in the SN model from latent periods of three to five days, there is no statistically significant difference between peak proportions at these values, suggesting the minor increase is simply due to chance. The overall general decline from latent periods of one to five days in both models can be explained by the interaction of final size and peak day (see Figure 7.6). While final size remains essentially the same, the peak day is increasingly delayed due to the longer period of time between generations of cases. Therefore, the epidemic peak is expected to become flatter to accommodate the same number of total cases within longer time frames.

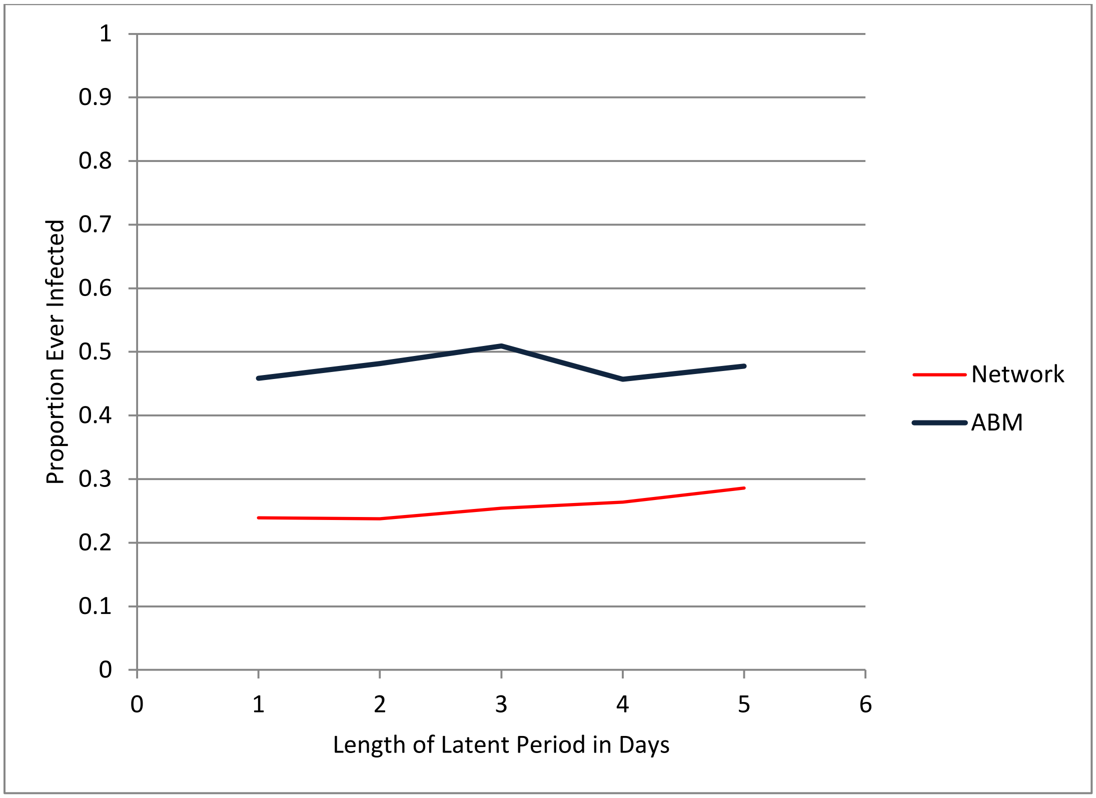


Figure 7.4. Final size of epidemics as the latent period is varied

The second qualitative difference between final and peak proportions is that the SN model produces larger peak proportions relative to the ABM for all values except one day, with the degree of distance generally increasing as the latent period lengthens. This relative difference is contrary to previous observations and expectations about the influence of the contact structure. In this case, the SN model may result in more consistent spread because of ensured contacts and relatively high degrees for most nodes. Under the right circumstances, one node could infect dozens of others at one time, resulting in more nodes in the infectious stage at any one time than would typically be possible in the ABM.

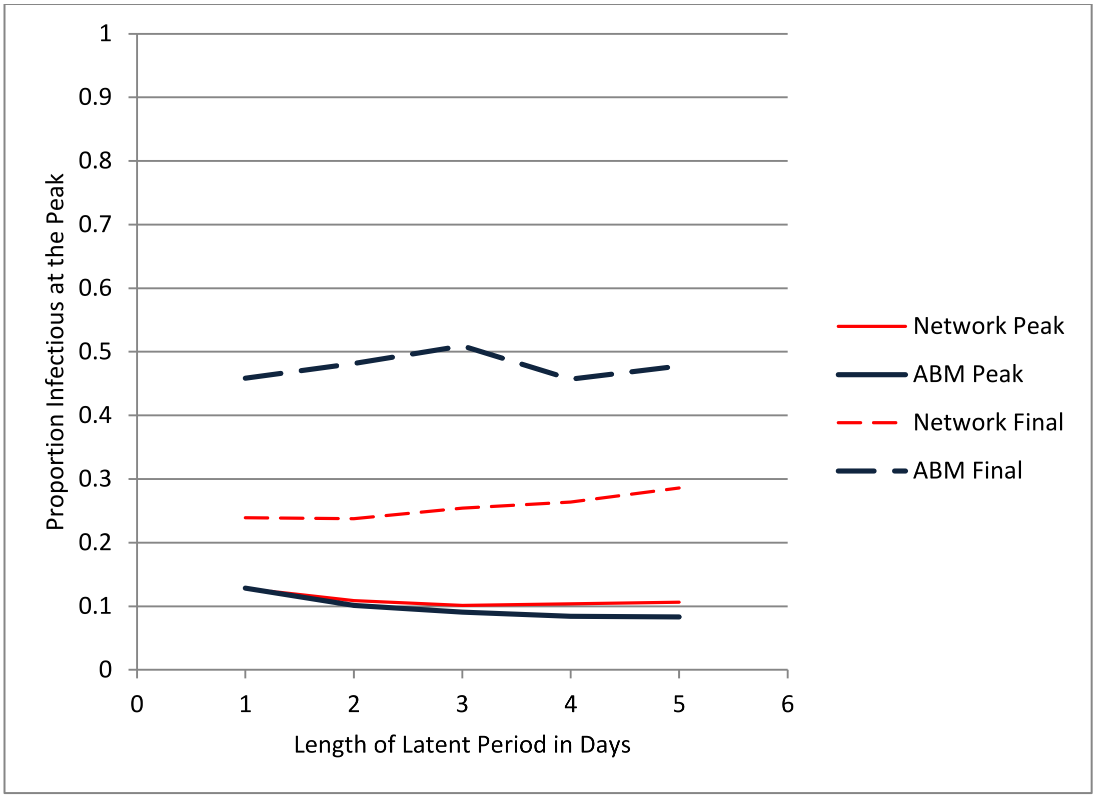


Figure 7.5. Proportion infectious at the peak and final proportions infected as the latent period is varied. The final proportions are included here to demonstrate the qualitative differences between the two measures.

For both models, peak day increases relatively linearly as the length of the latent period increases, reflecting the delay in generation time of infections (Figure 7.6). The most noticeable differences between the two models are at latent periods of three and four days. At the lower value, the ABM has a later peak day than would be expected and the SN model has an earlier one; at a latent period of four days, the pattern is reversed.

In the measures for last day (not shown), this trend is less marked for the SN model. Again, these differences may be due to the influence of church and visiting behavior around day three, particularly for the ABM.

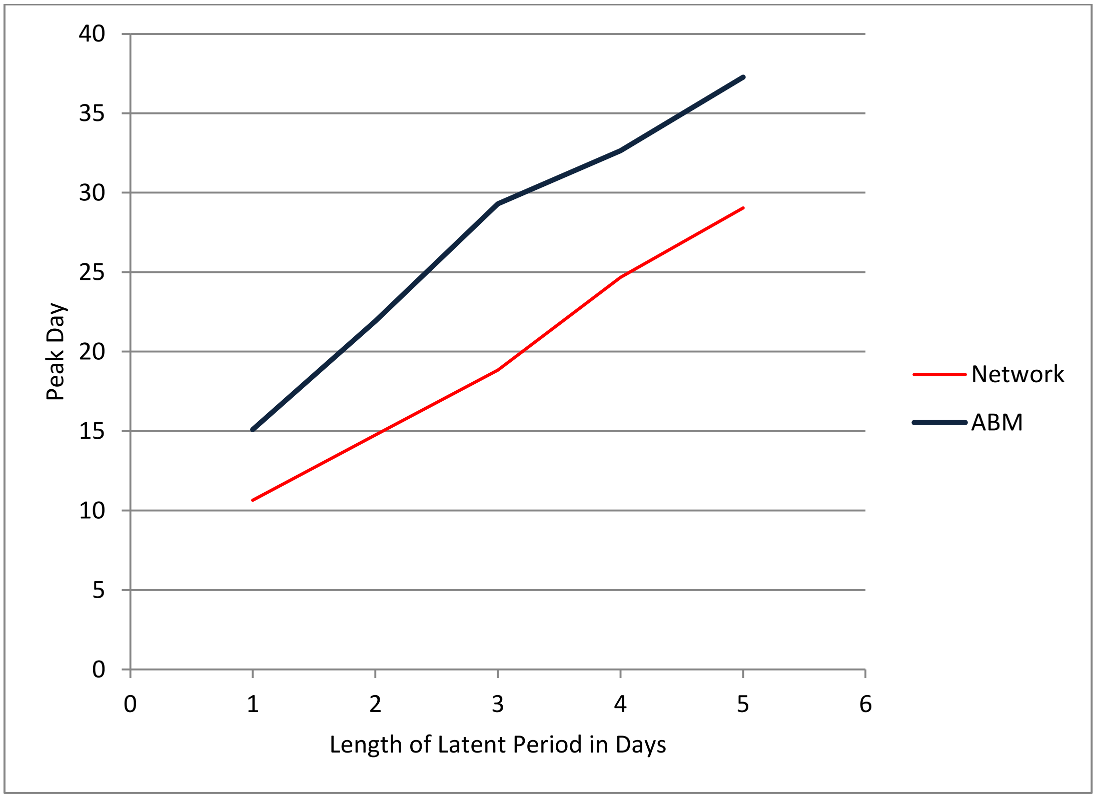


Figure 7.6. Peak day as the latent period is varied

Infectious Period

The infectious period parameter was varied from one to ten days (6 to 60 ticks) and, at least in measures of final size and peak day, appears to show some of the most noticeable qualitative differences between the two models out of all the parameters and values explored in these sensitivity analyses. Across the range of values, final size for both models increased from approximately 10% infected to approximately 90% infected for the SN model and even larger for the ABM (Figure 7.7). The ABM model follows a general logistic curve, with a rapid increase in epidemic size from infectious periods of 2 to about 7 days. The SN model likely also follows a logistic pattern, but within the range of parameter values tested, this shape is not clear. Rather, the SN model appears to have a relatively but not consistently linear increase in final size.

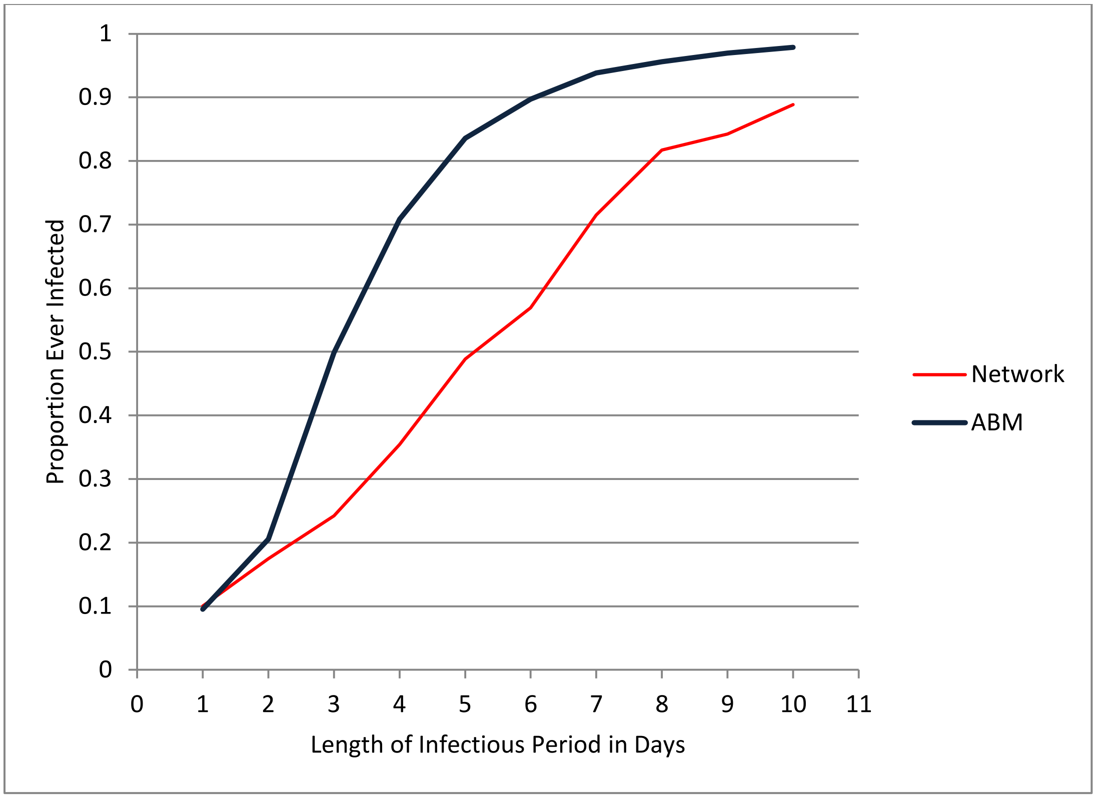


Figure 7.7. Final size of epidemics as the infectious period is varied

The overall increase in size for both models is easily explained by model structure; transmission can only occur when there is a contact between an individual who is susceptible and one who is infectious. The longer the infectious period, the more opportunities any one infectious individual has to contact susceptibles and thus generate more cases. The differences between the models is again most likely due to the static nature of the SN model. Each node has a predetermined number of contacts (linked nodes) and can never directly infect more than those nodes, and so the overall size is likely constrained as a result. Additionally, transmission of contacts are weighted but always possible in the SN model rather than associated with regular or periodic behavior, and so time-related parameters are assumed to have less of an impact than they would on the ABM.

Both models show a general linear increase in the peak proportion measure (Figure 7.8). However, the ABM, which starts at a lower peak proportion for the lowest two values of the infectious period, increases at a faster rate than the SN model. The ABM also appears to follow a steadier pattern, whereas the SN model fluctuates more at intermediate infectious periods. Differences between the models for this measure are less pronounced than differences in final size. The number of cases produced by the models may be “loaded” before or after the peak to account for similar peak size despite larger differences between final sizes at some durations of the infectious period.

Similar to final size, peak day values in both models follow a somewhat logistic pattern or shape as the duration of the infectious period lengthens, although the SN model appears to demonstrate a mostly linear increase within the range of tested values (Figure 7.9). The ABM model reaches a possible plateau around an infectious period of four days, suggesting longer infectious periods do not strongly affect the peak day. Explanations for this plateau and its absence in the SN model are not immediately apparent and require further testing.

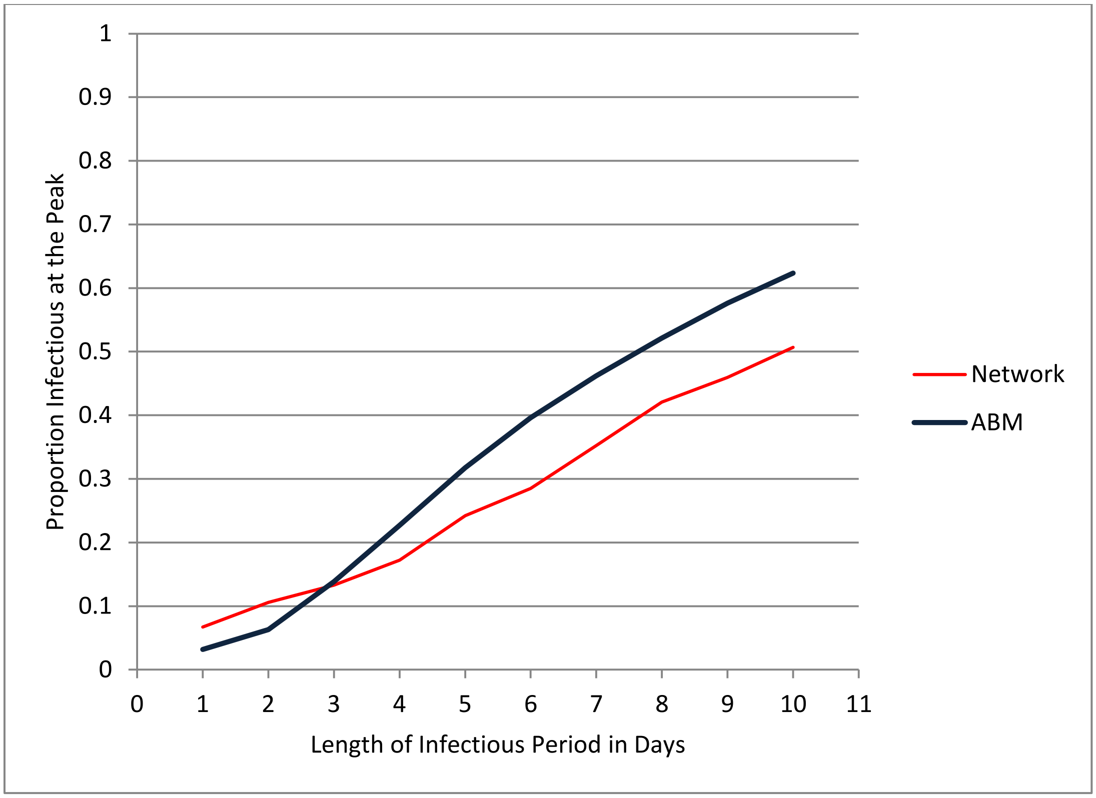


Figure 7.8. Proportion infectious at the peak as the infectious period is varied

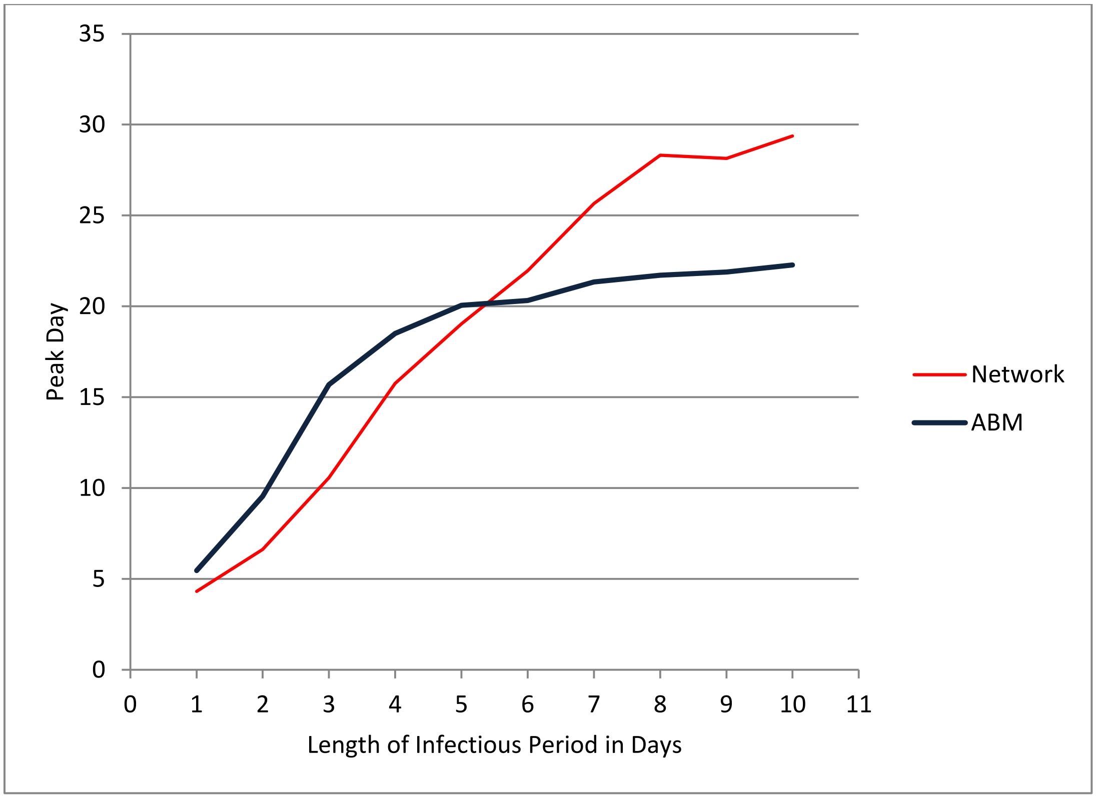


Figure 7.9. Peak day as the infectious period is varied

Mortality Probability

Like the transmission probability parameter, mortality probability was varied between 0.01 and 1.0, with most of the tested values in the range between 0.01 and 0.1. Final size measures suggest results for this parameter are most variable at these smaller values. Generally, the final sizes of epidemics decrease as the parameter increases from 0.01 to 0.1, and continue to decrease, albeit at a less steep slope, above those values (Figure 7.10). The overall decline is smaller for the SN model than for the ABM, and the ABM shows more fluctuation at moderate values than the SN model. Final sizes for mortality probabilities of 0.9 and 1.0 are notably different from the expected pattern. However, at these values, the number of epidemics is very small (no epidemics in the ABM, N= 4 out of 500 runs at 0.9 and 5 out of 500 runs at 1.0 in the SN model) as the simulated epidemic "dies out" before it can spread to a sufficiently large number of individuals; the outcome measures are thus influenced by these small sample sizes.

The overall decline in final size reflects this possibility of die-out. Even in simulations where enough individuals are infected to qualify the run as an epidemic (i.e. more than five percent of the population infected), transmission chains end prematurely as the number of deaths increase. The slightly larger size and less steep decline observed in the SN model at higher mortality probabilities likely reflects more reliable transmission across the static network. Because nodes are always connected to all contacts with at least some weight, potential transmission chains to secondary cases are longer and/or more numerous, even if a relatively large number of nodes die.

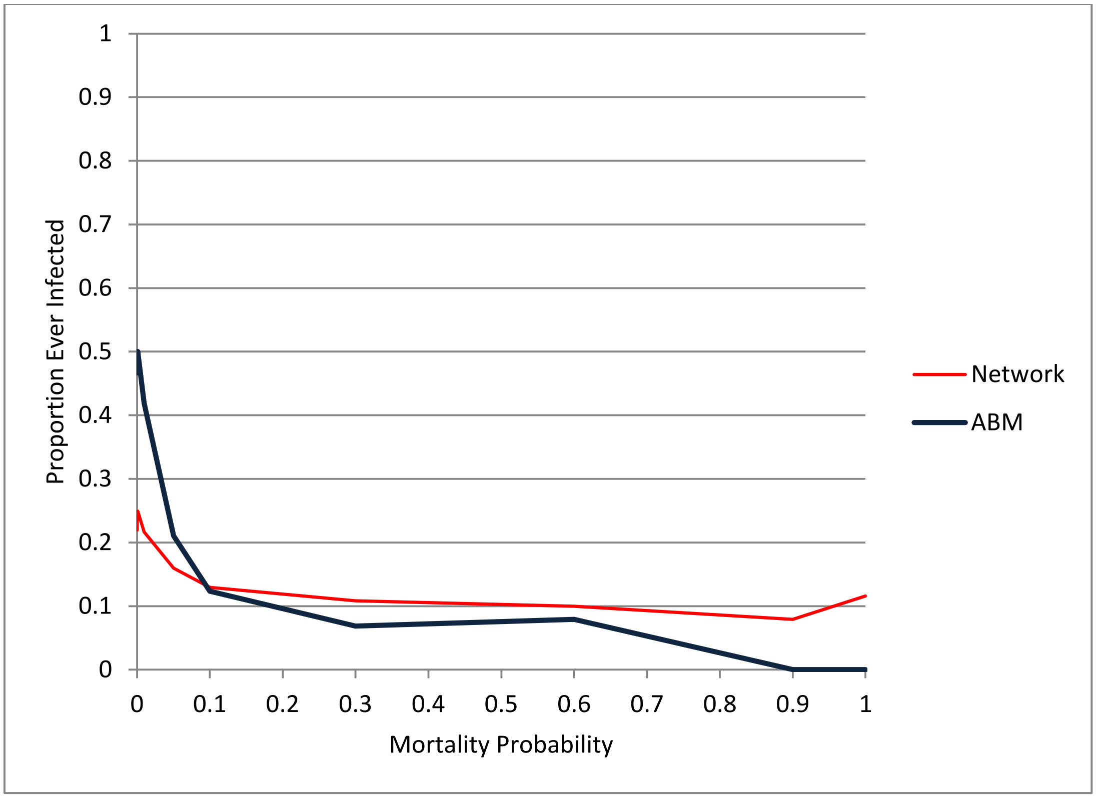


Figure 7.10. Final size of epidemics as the mortality probability is varied

Peak proportion measures show similar results, i.e. both models slightly decline in peak size as mortality probabilities increase from 0.01 to 0.1 and remain relatively stable or slightly decline across larger values (Figure 7.11). The SN model actually shows a slight increase from 0.1 to 0.3, but the proportions are not significantly different between these values (t = -0.81, df = 13, p = 0.43). Again, the peak sizes at 0.9 and 1.0 are quite different from each other and from the expected pattern within each model, due to the small number of epidemics at these mortality values. Further, as with the final size, the peak proportion is larger and arguably more stable in the SN model across most values of the mortality parameter.

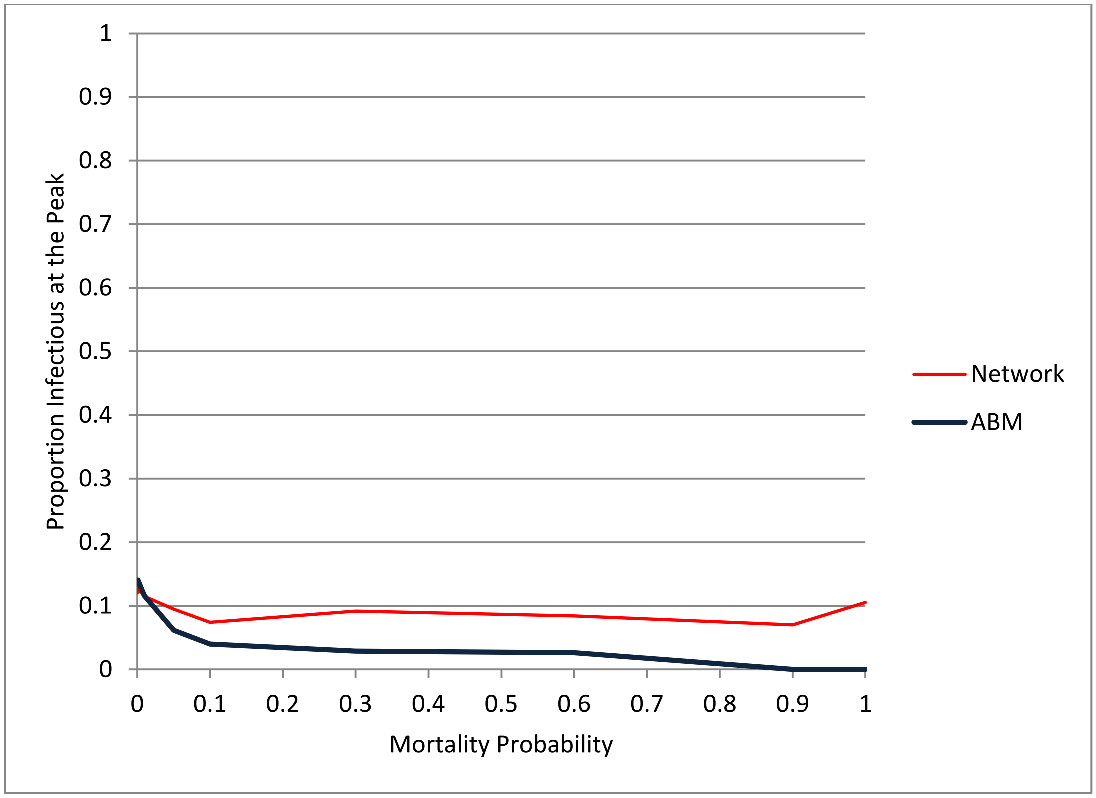


Figure 7.11. Proportion infectious at the peak as the mortality probability is varied

Peak day results show steep declines, i.e. earlier peak days, for both models as the mortality probability increases, particularly from 0.01 to 0.3. At values of 0.4 and above, the SN model demonstrates an approximate plateau, while the ABM continues to decline (Figure 7.12). As with size measures, the time measures at very high probabilities are influenced by the small number of epidemics and the increased likelihood of early epidemic burnout. The approximate plateau observed in the SN model corresponds with the larger sizes observed. Since at least a slightly larger portion of the population is infected, on average, epidemics require an average peak day that is late enough to account for at least one generation after the first case; however, because the mortality probability is so high, the epidemics will not last much beyond that.

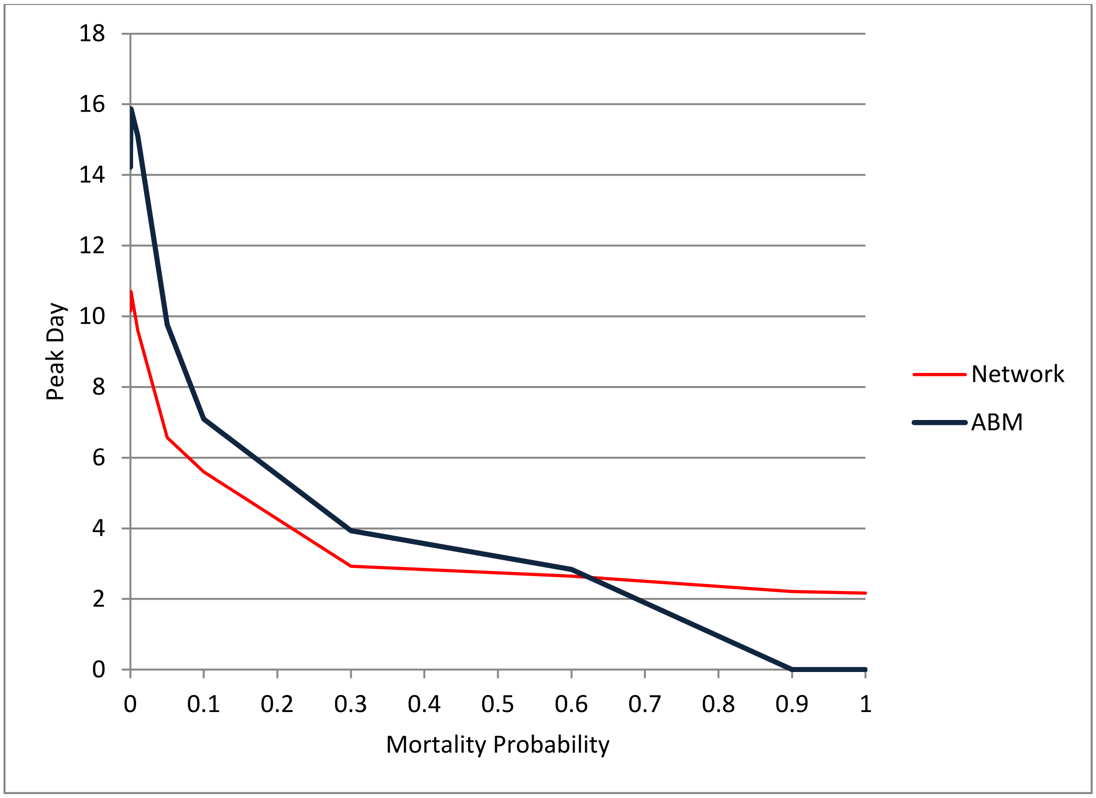


Figure 7.12. Peak day as the mortality period is varied

Estimated Influenza Epidemic Parameters

Both models were also run holding all parameters constant at values estimated from literature and observed data from the 1918 influenza pandemic. The latent and infectious periods were set to one and three days, respectively, as determined from literature (e.g. Ferguson et al., 2004; Mills et al., 2004). Mortality probability was calculated from death counts from the Greenspond region, resulting in a value of 0.0013. The transmission probability used in each model was chosen to achieve an attack rate of about 30%, corresponding to the minimum reported number of cases for the Greenspond region. For the SN model, preliminary analyses suggested a value of 0.065, while a transmission probabilty of 0.045 was more appropriate for the ABM. In the sensitivity analyses described above, the average of these values was used for consistent and simpler comparisons, as exact numerical results were less important than qualitative patterns. However, in the set of simulations below and in the results presented in the next chapter, the model-specific values were used so that each model produced desired behavior and values relevant to the research questions. Essentially, these are the values that would be chosen if each model had been the only one constructed for this research project. Therefore, these results allow for further consideration of the implications for choosing particular design strategies.

Table 7.1 provides the number of epidemics and final and daily outcomes for these parameter values. Both models produced epidemics about half of the time, although more simulations resulted in epidemics with the SN model. As expected, no significant differences were observed in the average final size since the parameter estimates were designed to generate a final size of about 30%. However, there were significant differences for all other measures. The SN model produces epidemics that are, on average, significantly larger and earlier. These trends can also be seen in Figure 7.13, which plots the average epidemic curve for both models. Most interestingly, with this combination of parameter values, the static SN model produces larger peak and final sizes, although the final size differences are not significant, and earlier peak and last days. These results are contrary to expectations from other studies that conclude that structural properties of social networks such as clustering may cause epidemics to become trapped and thus smaller and slower overall (e.g.Fefferman and Ng, 2007; Rahmandad and Sterman, 2008; Volz, 2010).

Table 7.1. Epidemic outcomes of both models using baseline parameters

Model	Number of Epidemics	Average Final Proportion	Average Peak Proportion	Average Peak Day	Average Last Day
SN	276	0.33	0.16	11.99	21.26
ABM	245	0.32	0.09	13.68	25.18
t-Test Results[a]	N/A	-0.56 (516)	-7.30* (356)	2.98* (496)	4.81* (490)

[a] Numbers in parentheses indicate degrees of freedom for the respective t-test. For all analyses, unequal variances were assumed; this calculation results in different degrees of freedom for each comparison despite the same number of observed values.

* $p < 0.05$

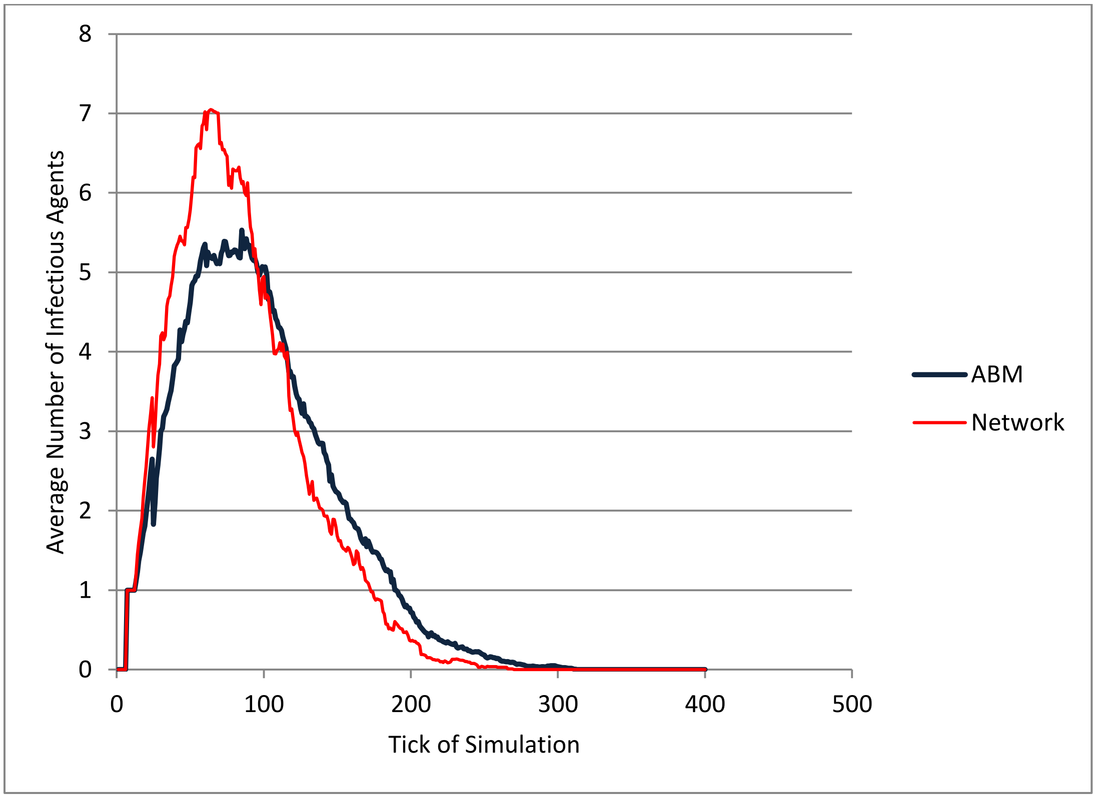


Figure 7.13. Epidemic curves for both models, averaged across all epidemic runs

Broad Comparisons and Implications for Model Design

Trends observed in the sensitivity analyses and simulations using estimated epidemic parameters provide insights regarding the impact of model structure, as well as particular parameters, on size and timing outcomes of epidemic simulations. Table

7.2 reiterates general trends observed with each of the parameters in the sensitivity analyses. Of the four parameters, changes in the duration of the latent period have the least effect on outcomes for both models. Changes in the transmission probability have large impacts on size and timing, particularly at lower and moderate values. Changes in the mortality probability have more of an impact on timing of epidemics, although some influence of the parameter on size is seen, particularly at low probabilities. The duration of the infectious period appears to produce the most notable qualitative differences between the two models, as well as marked variation within each model across the range of tested values. This impact is most likely due to a combination of factors – the infectious period is when transmission occurs, so it plays an important role in the spread of disease; the static structure of the SN model restricts potential paths along which this spread may occur; and timing-related variables are expected to have unpredictable or unimportant effects on SN model outcomes because contacts are not explicitly tied to periodic behavior or movement.

These results suggest several important implications for choosing a dynamic, agent-based or static, social network framework when designing epidemiological models. Few studies have explicitly compared static and dynamic network structures, especially not with the detailed, realistic behavior incorporated into these models. Despite previous studies frequently arguing that static networks produce smaller, slower epidemics than dynamic contact patterns, these comparisons show that the degree and relative difference in size and timing varies depending on the values of

Table 7.2. Broad trends and interpretations of the effects of different parameters

Outcome	Trend or observation
Final size	
Transmission Probability	Logistic increase
Latent Period	Horizontal, with slight increase or fluctuations at particular values
Infectious Period	Logistic increase; SN appears possibly linear
Mortality Probability	Decrease into approximate plateau; SN less marked
Peak size	
Transmission Probability	Logistic increase
Latent Period	Horizontal, but slight decrease as period lengthens
Infectious Period	Generally linear, possibly logistic increase for both; ABM increases faster
Mortality Probability	Decrease into approximate plateau; SN less marked
Peak day	
Transmission Probability	Linear increase to a maximum value, followed by shallower decline
Latent Period	Linear increase (later peaks)
Infectious Period	Logistic increase; SN appears possibly linear; ABM reaches approximate plateau
Mortality Probability	Steep, even exponential, declines; SN reaches more of a plateau
Differences between models	
Transmission Probability	Similar sizes at extreme values; ABM larger epidemics at moderate values. ABM slower at extreme values, SN model slower at moderate values
Latent Period	ABM larger final size, SN larger peak size; ABM slower epidemics and more influenced by church day
Infectious Period	ABM larger final and (typically) peak sizes; ABM slower at shorter periods/SN slower at longer periods
Mortality Probability	SN larger sizes except at very small probabilities; ABM later peak days until moderate or high probabilities (influenced by lack of epidemics)
Relative impact of parameter	
Transmission Probability	Large changes across values for both size and timing
Latent Period	Minimal impact on size measures; easily predicted pattern in timing
Infectious Period	Large changes across values for both size and timing; most noticeable qualitative differences between models
Mortality Probability	Noticeable impact at lower values, relatively little effect at higher values

important epidemiological parameters. Second, even when models are parameterized to achieve or estimate outcomes observed in real-world data, as is the case for the final size in the simulations reported in Table 7.1, other outcomes still vary significantly in different model designs. Selection of model structure and parameter values, therefore, must take into account aspects such as whether researchers are more concerned about size or timing measures, how different parameters affect transmission processes (e.g. the marked role of the infectious period in these examples) and the values of parameters for the specific disease being modeled, the types of behaviors and relationships included in the model design, and the availability of data to support these and other assumptions or to validate simulation results.

An important limitation in these analyses is that the parameters were only varied singly; sensitivity analyses on the initial St. Anthony model that informed construction of these models have shown that interactive effects of parameters can introduce additional patterns. For example, the effect of the latent period becomes more important if its duration is jointly varied with the duration of the infectious period. Whether similar interactive effects would be observed in these models is unknown. Future analyses will be conducted to examine model behavior under these circumstances.

Additionally, although the models were designed to be as similar as possible except for the dynamic vs. static contact networks, two major differences remain. First, the ABM includes random visiting, mostly of women and their dependent children, among households during a few daytime periods. Because of the random and infrequent nature of visitation, this behavior does not contribute to link strengths in the SN model. Further, only parents/caregivers are replaced upon death in the SN model while the ABM also replaces teachers and clergy. Although neither of these structural differences are expected to greatly impact the observed outcomes in the sensitivity analyses, at least some of the variation observed between models may be attributable to them. However, these differences may play a much larger role in the research questions discussed in the following chapter.

CHAPTER 8 – THE IMPACT OF DEMOGRAPHIC STRUCTURES AND ASSOCIATED SOCIAL BEHAVIORS ON EPIDEMIC OUTCOMES

Previous research into the 1918 flu and other epidemics indicates that individuals play different roles in the spread of disease and also are impacted to varying degrees in terms of morbidity and mortality. For example, general trends for the 1918 pandemic include differential mortality between the sexes and an unusual W-shaped age-specific mortality pattern where young adults were affected more than would have been expected based on other influenza data (e.g. Barry, 2005; Olson et al., 2005). These trends are often attributed to biological factors, such as effects from prior exposure or co-circulating pathogens, but they also correlate with social and cultural factors, such as regional involvement in World War I (e.g. Gagnon et al., 2013; Noymer and Garenne, 2000; Zylberman, 2003). Research into epidemic outcomes for demographic subgroups at the local population or community level can help determine the relative impact of these different factors and thus offer potential explanations for the wide variation in mortality observed during the 1918 pandemic.

The research questions investigated in this project focus on social and cultural factors that potentially influenced the spread of the flu and thus epidemic outcomes in traditional, kin-based communities. While types and frequencies of behaviors and relationships among specific individuals contribute heterogeneity to contact networks, general patterns observed in human societies also suggest that members of certain groups will engage in similar behavior and thus routinely come into contact with each other and members of other groups in systematic ways. The particular ecological and economic conditions of the study community influenced how families lived and worked together, resulting in notable, characteristic demographic structures like patrilineal settlement and patterns of behavior like women and children frequently participating in shore crews. It is important to determine whether any observed variation in epidemic outcomes between sex and age groups may be due to the behaviors and relationships associated with this type of household and community organization rather than to the biological attributes of the pathogen or individual hosts.

This project uses both the agent based-model (ABM) and social network (SN) model to explore the potential impact on disease spread of age- and sex-related social relationships and interactions in the study community. Only four major subgroups (based on the occ-type variable) are used in the analyses: fishermen (occ-type 1, n = 41), fisherwomen (occ-type 2, n = 17), “stay-at-home” mothers and dependent, preschool-aged children (occ-type 7/9, n = 32, hereafter referred to simply as mothers) and schoolchildren (occ-type 8, n = 21). Simulations were performed varying the group of the first case; five hundred simulations were performed for each scenario, but subsequent analyses were limited to only those runs which produced an epidemic, defined as more than five percent of the population infected.

Roles of the different subgroups were analyzed in two major ways. First, analyses considered the effect of different types of first cases on overall outcomes of size and timing. These results are important for understanding how the introduction and subsequent spread of a disease through a community affects the entire population. Second, epidemic experiences within the four subgroups are compared. These analyses investigate the range or severity of outcomes for particular members of a community that might be overlooked by analyses of community or population-level measures. In particular, the results demonstrate how sex- and age-related variation in morbidity may be produced by the behaviors of and relationships among members of different demographic subgroups. All results are presented below, followed by broader comparisons of the two models and implications of the results for understanding disease spread in small, traditional communities like Newfoundland outports.

Epidemic Outcomes

Epidemic outcomes, such as overall size and timing, emerge from the individual instances of transmission within the population. Some of the most important instances of transmission are those caused by the first case, as initial patterns of transmission strongly influence the likelihood of whether an epidemic occurs and its subsequent overall outcomes. Epidemiological research thus frequently considers the particular role and attributes of the first case in an otherwise susceptible population. Therefore, the analyses presented in this section investigate the differences in final and peak size and peak and last days for epidemics begun by first cases from the different demographic subgroups of fishermen, fisherwomen, mothers and schoolchildren.

In the ABM, average final and peak proportions and average peak days are significantly different when the group of the first case is varied, but the last day of infection is not (Table 8.1). For example, despite the use of a transmission probability estimated to achieve a target final size of 30%, values for this outcome vary between 31% for epidemics begun by fishermen or mothers up to 35% for epidemics begun by schoolchildren. In the SN model, all four epidemic outcomes, including last day of infection, are significantly different based on the first case. Additionally, the range of variation is larger in the SN model than in the ABM for most of the outcome measures. ANOVA tests like the ones presented here do not indicate which of the means are significantly different from each other so, as mentioned in Chapter 6, ad hoc t-tests were subsequently conducted to determine which groups contributed to the overall differences among group means (see Appendix D for details on the results from all ad hoc t-tests performed for this chapter).

Table 8.1. Epidemic outcomes varying the group of the first case

Model	Group of First Case	Number of Epidemics	Final Proportion	Peak Proportion	Peak Day	Last Day
ABM	Fishermen	239	.31	.091	14.74	26.06
	Fisherwomen	235	.32	.092	14.02	25.48
	Mothers	189	.31	.092	14.45	25.38
	Schoolchildren	342	.35	.107	12.41	24.57
ANOVA ($F_{3, 1001}$)			2.80*	7.43*	7.38*	1.19
SN	Fishermen	302	.31	.150	11.33	20.45
	Fisherwomen	259	.25	.129	11.10	18.88
	Mothers	221	.31	.156	12.89	21.58
	Schoolchildren	350	.33	.165	11.17	20.55
ANOVA ($F_{3, 1128}$)			5.64*	3.50*	3.79*	3.66*

* $p < 0.05$

These pairwise analyses indicate that the underlying patterns differ between the two models. In the ABM, all three significant differences are the result of epidemics begun by schoolchildren being larger and faster than epidemics begun by any other group. All other pairwise comparisons are not significantly different. These results indicate the importance of school-aged children in driving both the timing and size of epidemic spread in small communities. Particularly in the ABM, school attendance is the most consistent and frequent periodic behavior/movement bringing agents from multiple households into contact with each other. Fishing activities only produce contacts among, at most, a few households or adjacent crews, while activities such as church attendance and visiting are rarer or may only occur with some probability. Additionally, in the ABM, pairs of agents must be in neighboring cells for transmission to occur. The school is modeled as very packed or dense compared to other types of locations, so pairs of schoolchildren are generally more likely to be neighbors than pairs of agents in other buildings.

In the SN model, however, patterns are not as obvious or consistent. Pairwise comparisons indicate that, for final size, epidemics begun by fishermen, mothers and schoolchildren are significantly larger than those begun by fisherwomen. There are no significant differences between the other three groups, though. Peak proportion comparisons are similar, except there is no significant difference between fishermen and fisherwomen. Overall, the general pattern for the SN model is that epidemics begun by fisherwomen first cases are smaller than those generated by other first cases. This result is likely due to the relative position of these nodes in the network; women in this category provide a “bridge” connection between fishing crews and other members of the household. However, because these women may choose to engage in a variety of potential behaviors including fishing and remaining at home, their potential contacts are more dispersed or diluted than those made by members of at least some other subgroups engaged in more consistent behavior. Therefore, the relative position in the network and link strengths of nodes representing fisherwomen actually may decrease the likelihood of transmission from these individuals. Further analyses are required to confirm this hypothesis.

For the peak day measure in the SN model, fishermen, fisherwomen and schoolchildren all produce significantly earlier epidemics than first cases selected from mothers, but these three categories are not significantly different from each other. However, the pattern changes for last day, with fisherwomen epidemics ending significantly earlier than those begun by mothers and schoolchildren; the difference between fishermen and fisherwomen also approaches significance (p = .052). In the case of peak day, outcomes are likely explained by the relative position or role of mothers in the network. They are on the periphery of the network, connected to other families only through very weak links accounting for weekly church attendance and through members of their own household. These other members (schoolchildren, fishermen, etc.) must serve as intermediate contacts, resulting in slower initial spread on average. The last day measure is probably more an effect of epidemic size than the network position of fisherwomen. Because epidemics are significantly smaller when begun by these nodes, the process simply completes earlier on average.

Of interest is the relative unimportance of schoolchildren first cases in the SN model compared to the patterns observed in the ABM. This difference may also be due to the relative position and link strength of these nodes. Schoolchildren form the central "hub" of the network that connects all the other households and fishing boats and thus most frequently ensures a path through which disease spreads to the entire community. However, periodic behavior like daily school attendance may have less of an impact on outcomes in the SN model because contacts are distributed by weight and held static throughout a simulation. The strength of links between schoolchildren is larger than the strength of links connecting schoolchildren to individuals in other groups, even when those individuals are members of their own dwellings. In fact, taking into account different dwelling, household and boat combinations, the "average" link between schoolchildren is the strongest type of link in the SN model. The epidemic in effect may become "trapped" within the cluster of schoolchildren, at least initially, reducing the impact of this group on epidemic outcomes and explaining the nonsignificant results between them and other types of first cases.

Outcomes for Different Groups

In addition to overall measures of size and timing, epidemic outcomes for different demographic groups within a population are also expected to vary. As discussed above, general patterns of activities such as school attendance or sexual division of labor result in common or repeated interactions among particular individuals while reducing contact among others. This project explores the potential effects of these structured interactions in two ways. First, results presented in the next section explore outcomes across groups holding the group of the first case constant. This approach investigates the relative effects of particular first cases on epidemic outcomes based on their interactions with different subgroups. In the second section below, results are presented for analyses comparing outcomes within particular groups varying the group of the first case. These analyses can suggest whether observed outcomes may be due more to the role or activities of the group within the community rather than the characteristics of the first case specifically.

Outcomes considered in these analyses include the average day that members of each group were infected and the average proportion of each group that were ever infected. In epidemics where no members of a particular group were infected, a proportion of 0 is meaningful and included in analyses; however, no average day infected for the group could be calculated for those simulations. Calculation of the measures excluded members of each group who were never infected, as well as any member who was the first case for a particular run.

An important consideration for determining these outcomes is the possibility that individual agents or nodes may change occ-types during the course of a simulation due to replacement of others who died. This concern was larger for the ABM, since the SN model only replaced caregivers, while the ABM also replaced vital community roles of clergy and teachers. Output recorded by the models only indicates the occ-types of individuals at the end of a simulation, but the infection may have occurred before or after the replacement. Therefore, individuals were only analyzed for the occ-type to which they were assigned at the beginning of a simulation, and their data were included in the analyses for that occ-type even if they switched roles at any point. Due to the low value of the mortality parameter, the majority of runs did not include any replacements;

those that did usually only involved one member of a particular occ-type and so likely did not greatly impact averages.

Outcomes across groups holding the group of the first case constant

Analyses suggest the characteristics of the first case significantly impact group-specific outcomes. As indicated in Table 8.2, epidemics in the ABM begun by all types of first cases except fishermen[1] produce significant differences in the average day members of the four subgroups were infected. For example, when a fisherwoman is the first case, the average day infected ranges between 11.6 days for schoolchildren and 13.2 days for mothers. Again pairwise comparisons were conducted for each of the ANOVA analyses to determine which groups contributed to the overall difference (see Appendix D). These comparisons demonstrated relatively consistent patterns such as schoolchildren being infected significantly earlier than at least some other groups when fisherwomen, mothers or schoolchildren were the first case. Additionally, fisherwomen were infected significantly later than other groups when mothers or schoolchildren were the first case, but not when other fisherwomen were.

In the SN model, all types of first cases produced significant differences in average day infected (Table 8.2). These differences were even more consistent than in the ABM. When fishermen or fisherwomen were the first case, mothers were infected significantly later than all other groups, none of whom were significantly different from each other. When mothers or schoolchildren were the first case, fisherwomen were infected significantly later than all other groups. Additionally, schoolchildren were

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[1] Note the *p* value when fishermen were the first case is 0.06.

infected significantly earlier when other schoolchildren were the first case. Broadly speaking, results for both models indicate both the important role of school-based interactions in driving epidemics, since schoolchildren were often infected earlier and produced significant differences in outcomes for other groups. These results also highlight the more peripheral interactions of fisherwomen and mothers, since these groups were often infected significantly later than other groups.

Table 8.2. Average day infected for different groups based on the group of the first case

Model	Average Day for Group:	Group of First Case Fishermen	 Fisherwomen	 Mothers	 Schoolchildren
ABM	Fishermen	11.9	11.9	12.7	11.5
	Fisherwomen	12.7	12.3	14.2	12.2
	Mothers	13.4	13.2	12.0	11.4
	Schoolchildren	12.3	11.6	11.2	8.7
ANOVA (F)[a]		2.53 (3, 889)	2.62* (3, 872)	8.34* (3, 752)	36.43* (3, 1364)
SN	Fishermen	9.0	8.5	10.3	9.8
	Fisherwomen	9.6	8.5	12.1	11.3
	Mothers	10.7	10.6	10.3	9.9
	Schoolchildren	9.4	9.2	9.8	7.5
ANOVA (F)[a]		4.58* (3, 1102)	5.75* (3, 924)	5.42* (3, 829)	28.44* (3, 1288)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each group produced a different number of simulations resulting in epidemics.

* $p < 0.05$

Similarly, the average proportion of infected individuals varies significantly among different groups when the group of the first case is held constant (Table 8.3). Pairwise comparisons demonstrate consistent patterns for both models. A significantly larger proportion of schoolchildren are infected than individuals in other groups, regardless of model structure or group of the first case, while a significantly smaller proportion of mothers are infected.

Table 8.3. Average proportion infected for different groups based on the group of the first case

Model	Average Proportion for Group:	Group of First Case			
		Fishermen	Fisherwomen	Mothers	Schoolchildren
ABM	Fishermen	.30	.32	.30	.33
	Fisherwomen	.27	.26	.25	.29
	Mothers	.24	.24	.24	.28
	Schoolchildren	.44	.43	.43	.50
ANOVA (F)[a]		38.45* (3, 952)	33.51* (3, 936)	28.67* (3, 752)	85.33* (3, 1364)
SN	Fishermen	.30	.26	.30	.31
	Fisherwomen	.29	.22	.27	.27
	Mothers	.23	.18	.22	.25
	Schoolchildren	.41	.32	.44	.47
ANOVA (F)[a]		22.62* (3, 1204)	16.53* (3, 1032)	30.29* (3, 880)	48.82* (3, 1396)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each group produced a different number of simulations resulting in epidemics.

* $p < 0.05$

The proportion of fishermen and fisherwomen are less consistent, and indicate some differences between the two models. In the ABM, fewer fisherwomen are infected (i.e. a significant difference between this group and fishermen, but not between fisherwomen and mothers) in all cases, except when the first case is a fisherman, possibly reflecting more frequent contacts between fishermen and fisherwomen in the same crews. A somewhat opposite trend is seen in the SN model, i.e. there is no significant difference between the proportions of fishermen and fisherwomen, both of which are significantly larger than the proportion of mothers infected, except when fisherwomen are the first case. In these simulations, the proportion of fisherwomen infected is significantly smaller than fishermen but still significantly larger than mothers. These proportions in the SN model may reflect the relatively weak “bridge” roles of fisherwomen described earlier.

Outcomes within specific groups varying the group of the first case

An alternative way of comparing these outcomes is to analyze how measures are affected within specific groups as the group of the first case varies. For example, in the ABM, there is no significant difference in average day or average proportion infected for fishermen, regardless of the group of the first case. In the SN model, there is a significant difference in the average day measure (Table 8.4). Pairwise comparisons for the SN model indicate that fishermen become infected significantly earlier when fishermen or fisherwomen are the first case than when mothers are the first case, and when fisherwomen are the first case than when schoolchildren are. These differences likely reflect the relative position of members of the different groups in the network model and the weight of the links between them. Mothers and schoolchildren are linked with any substantial weight only to the fishermen in their households, likely resulting in less direct transmission to fishermen in general. The weights of links between fishermen and others in their group or fisherwomen are larger, at least among members of the same crew, and so on average would require fewer attempts/time steps or intermediate infections to transmit the disease. More importantly, the position of fishermen on the “spokes” of the network (apart from weak church connections, only members of their households link them to the larger component) could explain why there is no significant difference for most of the measures regardless of the first case.

Table 8.4. Outcomes for fishermen varying the group of the first case

Model	Group of First Case:	Outcome for Fishermen	
		Average Day Infected	Average Proportion Infected
ABM	Fishermen	11.9	.30
	Fisherwomen	11.9	.32
	Mothers	12.7	.30
	Schoolchildren	11.5	.33
ANOVA (F)[a]		2.00 (3, 990)	0.98 (3, 1001)
SN	Fishermen	9.0	.30
	Fisherwomen	8.5	.26
	Mothers	10.3	.30
	Schoolchildren	9.8	.31
ANOVA (F)[a]		5.37* (3, 1115)	2.19 (3, 1128)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each comparison considered a different number of simulations resulting in epidemics.
* $p < 0.05$

For fisherwomen, the group of the first case produces significant differences in average day infected in both the ABM and SN model (Table 8.5). However, pairwise comparisons show some differences between the two models. In the ABM, fisherwomen are infected significantly later when mothers are the first case but no differences are seen for other comparisons. Similarly, in the SN model, fisherwomen are infected significantly later when mothers are the first case. However, fisherwomen are also infected significantly earlier when other members of their group are the first case compared to runs where fishermen or schoolchildren are the first case. The lesser impact of mothers is probably best explained by the potentially limited interaction between those individuals and fisherwomen, even those who reside in the same dwelling. Fisherwomen have a high likelihood of going to the boats or visiting other households independently, while mothers also frequently visit. Behaviors such as remaining at home rather than choosing to work in the shore crew also likely explain the differences observed with fisherwomen first cases. Although these nodes form weak bridges between crews and households as discussed, the link strengths between fisherwomen are typically stronger than between fisherwomen and fishermen or schoolchildren. Additionally, these differences may simply be due to the overall faster epidemics produced by fisherwomen first cases.

Table 8.5. Outcomes for fisherwomen varying the group of the first case

Model	Group of First Case:	Outcome for Fisherwomen Average Day Infected	 Average Proportion Infected
ABM	Fishermen	12.7	.27
	Fisherwomen	12.3	.26
	Mothers	14.2	.25
	Schoolchildren	12.2	.29
ANOVA (F)[a]		4.60* (3, 901)	2.05 (3, 1001)
SN	Fishermen	9.6	.29
	Fisherwomen	8.5	.22
	Mothers	12.1	.27
	Schoolchildren	11.3	.27
ANOVA (F)[a]		16.25* (3, 982)	4.20* (3, 1128)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each comparison considered a different number of simulations resulting in epidemics.

* $p < 0.05$

The average proportion of fisherwomen infected varies significantly only in the SN model. Comparisons among different first cases indicate that this difference is driven by simulations where fisherwomen are also the first case. In these simulations, the average proportion of fisherwomen infected is significantly smaller than when a member of any other group is the first case. These outcomes are most likely due to the very weak connection between fisherwomen who are not assigned to the same crew or dwelling, as well as to the overall significantly smaller size of epidemics begun by these individuals.

The outcomes for mothers (and dependent children) are also influenced by the first case of an epidemic (Table 8.6). While there is no significant difference in average day infected in the SN model, mothers in the ABM are infected, on average, significantly earlier when other mothers are the first case than when fishermen are, and when schoolchildren are the first case than when fishermen or fisherwomen are. These results likely reflect the important role of schoolchildren observed in the ABM in other measures, as well as the close relationship between mothers and dependent children assigned to the same dwelling and frequent visitation to members of this group in other dwellings (behavior which is not accounted for in the SN link strengths).

Pairwise comparisons also demonstrate differences between the two model structures in measures of average proportion of mothers infected. In the ABM, epidemics begun by schoolchildren again drive the observed differences; more mothers are infected when schoolchildren are the first case than when any of the other groups are. However, in the SN model, the observed differences are due to fisherwomen first cases; in these simulations, significantly fewer mothers are infected than when the first case is from any other group.

Table 8.6. Outcomes for mothers varying the group of the first case

Model	Group of First Case:	Outcome for Mothers Average Day Infected	 Average Proportion Infected
ABM	Fishermen	13.4	.24
	Fisherwomen	13.2	.24
	Mothers	12.0	.24
	Schoolchildren	11.4	.28
ANOVA (F)[a]		7.93* (3, 941)	4.17* (3, 1001)
SN	Fishermen	10.7	.23
	Fisherwomen	10.6	.18
	Mothers	10.3	.22
	Schoolchildren	9.9	.25
ANOVA (F)[a]		0.90 (3, 1014)	7.04* (3, 1128)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each comparison considered a different number of simulations resulting in epidemics.

* $p < 0.05$

Finally, schoolchildren outcomes are also influenced by the group of the first case (Table 8.7). In measures of average day infected for both models, schoolchildren are infected significantly earlier when other schoolchildren are the first case compared to all other groups, reinforcing previous observations about the importance of this regular behavior within a densely packed social space. Additionally, in the ABM, schoolchildren are infected significantly later on average when fishermen are the first case than when mothers are. This latter difference is counterintuitive because, considering only agents assigned to the same dwelling and thus crew, schoolchildren have an equal chance of being neighbors with any of these individuals during the evenings. Only Saturday behavior would produce the most difference in likelihood of transmission; older schoolchildren have a high chance of going to the boats with fishermen, while younger children who do not choose to “play” at school have a reasonable chance of remaining home or visiting with the mothers and preschool children in the household. The majority of the schoolchildren in the community fall into the "older" category, which would predict more interaction with fishermen. However, the model begins on a Monday, and so the first Saturday in the simulation may be too late to have a meaningful impact on time or speed of transmission, while some unidentified factor may be responsible for the earlier infection times seen with first cases drawn from mothers.

Table 8.7. Outcomes for schoolchildren varying the group of the first Case

Model	Group of First Case:	Outcome for Schoolchildren Average Day Infected	 Average Proportion Infected
ABM	Fishermen	12.3	.44
	Fisherwomen	11.6	.43
	Mothers	11.2	.43
	Schoolchildren	8.7	.50
ANOVA (F)[a]		28.67* (3, 938)	4.39* (3, 1001)
SN	Fishermen	9.4	.41
	Fisherwomen	9.2	.32
	Mothers	9.8	.44
	Schoolchildren	7.5	.47
ANOVA (F)[a]		11.21* (3, 1032)	8.98* (3, 1128)

[a] The numbers in parentheses indicate the degrees of freedom for each ANOVA analysis, which vary because each comparison considered a different number of simulations resulting in epidemics.
* $p < 0.05$

Measures of average proportion infected show that significantly more schoolchildren are infected in the ABM when other schoolchildren are the first case than when a member of any other group is. This outcome is also observed in the SN model, except that there is no significant difference between simulations with schoolchildren or mothers as the first case. Additional pairwise comparisons are significant in the SN model as well; the proportion of schoolchildren infected is also significantly larger when fishermen or mothers are the first case than when fisherwomen are, again likely a result of the weak bridge role played by fisherwomen.

Model Comparisons and Implications

These analyses demonstrate similarities and differences between the two models when the group of the first case and/or group-specific outcomes are considered. The most notable similarity between the two models is that significant differences are most often produced by behaviors or relationships involving schoolchildren and adult women (whether mothers of dependent children or fisherwomen). The most notable difference between the two models, however, is that the schoolchildren effects tend to be more consistent or overwhelming in the ABM, whereas the SN model seems to be more often influenced by the relationships and relative network positions of adult women. Additionally, the ABM demonstrates more instances where there are no significant differences in epidemic outcomes when the first case is varied.

As discussed, the important role of the school, particularly in the ABM, is likely due to the regular interactions among schoolchildren from most households in the community, which take place in a densely packed institution and begin immediately in a simulation when there are many susceptible individuals. The large, tightly packed cluster representing the school in the SN model connects all of the “spokes” more strongly than the two churches or adjacent boat interactions do, explaining why schoolchildren often have a significant impact on SN model outcomes as well. However, in the SN model, school attendance behavior simply contributes to the static weight links and so is not as associated with time-dependent behavior, and the strengths of the links among schoolchildren relative to their links to others in the community also may result in the epidemic becoming trapped within the school. Additionally, the relative position of adult female nodes, such as the proposed “bridge” role of fisherwomen, as well as the absence of links for visiting among dwellings due to the exceedingly low strength such behavior would contribute, likely explains why the spread of disease is more sensitive to these types of nodes in the SN model.

These results have several important implications, particularly for studying epidemic spread in small, traditional, and/or historical communities. First, the activities and relationships, including kinship connections, of women and children are often under-recorded in archival sources and more assumptions might need to be made about their behaviors or interactions with each other. For example, in sources for the study community, descriptions of women’s contributions to the household and fishing crews were often more detailed than discussion of activities such as visiting or membership in social or charitable organizations. In traditional Newfoundland and Labrador communities, visiting among households, as well as participation in church or other associations, often provided women means of developing relationships outside of the patrilineal-based households and communities they married into. Incorporation of this behavior thus gives more insight into the types of activities that might influence disease spread, produce differential sex outcomes, and vary based on the traditional structure of the community under study. However, due to lack of detailed data to inform this behavior, arbitrary decisions about the frequency of visiting were required in model construction, while the models may also overemphasize the degree to which women participated in the shore crews. In epidemics like the 1918 flu where notable and unusual differences were seen in mortality outcomes among certain age classes or between the sexes, assumptions about behavior of groups underrepresented in the literature take on additional importance, especially if there is limited morbidity data or the case fatality rate is unknown or poorly estimated. The results here suggest that, even with all disease-related parameters and individual susceptibility and health history being equal, differences among demographic groups may still be observed solely due to the patterns of behavior and types of interactions engaged in by members of a community. However, those results are only as valid as the assumptions made about those behaviors and interactions.

Related to this concern, the study community in this project exemplified a particular sexual division of labor based on the subsistence economy of the region that also influenced household structure, kinship, and other activities. Fisherwomen, i.e. adult women who participated in shore crews, often produced epidemics that were smaller and earlier than those produced by other groups, at least in the SN model. Additionally, fewer of these women were typically infected, and their average time of infection was later than other groups. These differences were somewhat surprising, as these women can be considered additional links between groups that would not be present in communities with a stricter sexual division of labor. However, their irregular behavior (which included whether they participated in the shore crew, stayed at home, or independently visited others) might ultimately weaken their bridge potential by spreading contacts too thin. This weakening is less apparent in the ABM, probably partly because of the better incorporation of visiting behavior. Nonetheless, these results demonstrate the importance of considering how variation in the sexual division of labor may impact disease outcomes in societies with different types of organization.

Third, although previous research has indicated the important role of schoolchildren on the spread of disease, these studies often examine contemporary Western communities. In historical communities such as Newfoundland and Labrador outports in the early 20th century, school attendance likely fluctuated with season or age, and some communities may not have even had schools; similar concerns might be present even for contemporary communities, such as those in developing countries. Therefore, the impact of this institutional behavior on model outcomes currently represents a maximum baseline and may have much less influence if irregular or declining attendance is incorporated in future versions. The decision to include school behavior or other activities in which children aggregate in epidemiological models, especially without strong historical or ethnographic support for such inclusion, could vastly overestimate the impact of school-aged children on disease spread.

Extensions of the models to communities characterized by other types of labor division, household structure or marital and settlement patterns, as well as extensions to other time periods or epidemics, would allow for deeper understanding of how gender, age, kinship, and traditional subsistence or economic activities can produce very different epidemic outcomes. Additionally, gender may play a role in how epidemics are introduced into communities, especially isolated ones like Newfoundland outports. Typically, women did not travel between communities, so it is likely that the disease would have been brought in by an adult man, such as a traveling pastor or a fisherman. However, the frequency or likelihood of travel would depend on the season; additionally, women and children occasionally accompanied men on long trips such as to the Labrador fishery or lumber camps. Finally, neither model accounts for disease-related changes in behavior. Women were typically the caretakers of ill family members, even in communities with medical personnel. This feminine role was especially noted during the crisis events of World War I and the 1918 pandemic. Therefore, mothers and fisherwomen who play a minor or peripheral role in regularly daily interactions, particularly in the network model, would be expected to take on much more vital roles during an epidemic that would bring them into frequent contact with both infectious and susceptible individuals.

Generally, results indicate that age- and sex-related roles in a community can greatly affect epidemic outcomes for particular groups as well as population-level measures of epidemic size and timing. Additionally, these results further support arguments made in this research project that the choice of model structure can produce different results and so must be considered carefully. Overall, analyses demonstrate the usefulness of studying small-scale disease spread for understanding how social, cultural, individual and random factors might have combined with biological or disease-related parameters to produce the regional variation in outcomes observed for the 1918 pandemic.

CHAPTER 9 – CONCLUSIONS

This project addressed both conceptual questions related to the important social and behavioral factors affecting disease spread in small traditional communities, and methodological questions designed to test the applicability and appropriateness of different assumptions commonly made in epidemic modeling research. As these two complementary avenues of research developed, the project progressed in three overlapping stages: construction of the model population, development of the epidemic simulation models, and analyses of model results.

Construction of the Model Population

The first stage involved gathering and evaluating ethnographic and historical sources, as well as data specific to the study community, from fieldwork and print and online resources. This data collection stage was guided by concerns and expected needs for later stages of the project, such as identifying common daily behaviors to include in the simulation models. The primary goals of this stage, however, were to verify details about daily life in the study community beyond the general ethnographic descriptions of other Newfoundland communities, and to gather sufficient information on members of the study community for family reconstitution.

Numerous sources indicated common features of daily life in the study community region, including involvement of families in a variety of seasonal, marine-based occupations; detailed descriptions of activities engaged in by men, women and children; the presence of schools and churches; and the proximity of medical personnel.

Because of the economic and administrative importance of the Greenspond region, several unique features of the community were also noted, such as the relatively large population size, diversity of employment opportunities, and the presence of a courthouse and other institutions not commonly found in Newfoundland outports. Many of these unique features were not considered in the current models, in order to make them more generalizable, but indicate possible avenues for continued research.

Findings from this stage of research also allowed for identification of family relationships among households in order to establish extended kin relationships for the five main families recorded in censuses for the study community. Patterns of patrilineal kin-based crews were well documented and consistently observed for pre-Confederation Newfoundland populations (Firestone, 1967; Nemec, 1972; Queen and Habenstein, 1974). Therefore, relationships identified during the family reconstitution process could be used to assign members of the model population to realistic crews. Fortunately, most vital statistics and parish records, genealogical sources and other data allowed for relatively easy assignment of males to these crews. In the case of several households, relationships were hypothesized based on reasonable assumptions about age, surname and other information; inaccurate assignment of these individuals are not expected to meaningfully impact the results or conclusions of this study. Kinship connections among adult, married women were less straightforward, often due to a lack of information on maiden names or places of birth. Types of activities included in the model, however, are largely related to daily life of households and crews, so these matrilineal connections were less relevant. Nonetheless, consideration of these relationships, where known, should be one focus of future analyses. Altogether, the ethnographic and archival sources allowed for the construction of a model population similar in characteristics to the study community, with individuals allocated to several age and sex groups, as well as to different households, dwellings, and churches.

Development of the Epidemic Simulation Models

The model population developed from the family reconstitution stage, combined with information on daily life and characteristics of the 1918 pandemic in Newfoundland, contributed to the development of two individual-based models. An important aspect of model design was determining the level of detail necessary to accurately capture the factors influencing disease transmission in populations like the study community, without specifying the models in such detail that the results cannot be generalized. Both models reflect general daily behaviors of community residents, such as school and church attendance and participation in fishing crews. When disease transmission processes are modeled, the individual behaviors are able to produce epidemic patterns consistent with those observed in epidemiological literature, such as the general shape of curves that indicate the number of people infected and random extinctions of disease outbreaks.

The two models were designed to allow for explicit testing of hypotheses related to structure and assumptions about contact networks. The agent-based model (ABM) allows for regular and random movement to important social spaces like dwellings, crews, schools and churches. This movement often occurs with some probability and allows for a dynamic, or constantly changing, contact network to emerge during simulations. The social network (SN) model was constructed to emphasize known or presumed social relationships believed to play important roles in disease transmission. These relationships are established prior to epidemic simulations and generally do not change. All other features of the models were kept as similar as possible, in order to home in on how these fundamental assumptions about how social interactions are structured can affect model results. Similar model designs are often chosen by epidemiological researchers based on specific research questions, the desired level of detail or complexity, and the available data and computing resources. The choice of model can have significant implications for the conclusions and implications drawn from model results.

Analyses of Model Results

Simulations of the models were analyzed in two major ways: sensitivity analyses to determine how assumptions about model structure affect output, and testing of research questions to investigate potential impacts of different demographic subgroups on disease transmission in small, traditional communities. In both cases, multiple epidemic simulations were performed for both models in order to compare different outcomes. For the sensitivity analyses, these outcomes included overall measures such as final and peak size. Research questions related to demographic subgroups also compared these overall measures, as well as group-specific outcomes of average day and proportion infected.

Sensitivity analyses indicated important differences in model behavior and outcomes, primarily related to the static contact network in the SN model compared to the dynamic contact network in the ABM. For example, across the tested range of different parameters, the ABM frequently produced larger final sizes than the SN model. Second, some of the most interesting differences in qualitative results were observed in analyses varying the length of the infectious period. This parameter is influenced both by simplifying assumptions about the biological nature of transmission (i.e. in the models, disease spread can only occur when the transmitting individual is in the infectious category) and by how regular or time-dependent behavior is considered in the different models. The ABM explicitly considers different types of behaviors at different times during a simulated epidemic, whereas links in the SN model are assigned static weights implicitly accounting for different activities throughout a week. Finally, when baseline parameters estimated for the 1918 pandemic were used in simulations, the SN model produced epidemics with, on average, significantly larger, earlier peaks than the ABM. Commonly, research studies aiming to understand the system of disease transmission in historical and modern epidemics and/or to make public health recommendations for prevention or control strategies focus on the size or timing of epidemics produced in different model scenarios. These sensitivity analyses indicate the design features used in a model can significantly affect those measures and so should be carefully considered when constructing models and interpreting results.

Analyses addressing the impact of demographic subgroups were driven by several considerations. Women’s and children’s activities are often overlooked or underexplored in historical and occasionally ethnographic reports of traditional communities, and thus models present one potential research method for addressing these gaps in literature by allowing researchers to explore the range of possible outcomes when different behaviors, such as frequency of school attendance, are varied. Further, the “unusual” pattern of sexual division of labor commonly seen in fishing communities like Newfoundland outports, wherein women frequently participated in the subsistence and economic activities of processing fish in addition to other tasks, has been noted by several writers (e.g. Porter, 1985), suggesting the importance of understanding how these behavioral patterns could affect disease outcomes and short- and long-term demographic impacts. Finally, consideration of different demographic subgroups is particularly important for studies of the 1918 flu because of its well-known W-shaped age-specific mortality pattern reflecting the increased likelihood of young adults dying and sex differentials in mortality caused by both biological and social factors in different regions (see, for example, Noymer and Garenne, 2000; Olson et al., 2005; Zylberman, 2003). Analyses such as the ones in this study might help tease apart how much of the observed variation in age- and sex-specific outcomes is due to biological or sociocultural factors.

Results of the analyses for this question highlighted several important findings. Notably, in the ABM, epidemics were largely driven by schoolchildren, although this group was less influential in the SN model. The SN model captured significant differences in outcomes for adult women, both in timing and proportion affected, that might be masked by the dynamic nature of the contact network and/or random visiting in the ABM. It remains unclear which, if any, of these findings, more accurately reflect disease outcomes in real-world populations. While some of the differences are undoubtedly due to different assumptions about the structure of the models, it is unlikely that methodological issues alone sufficiently explain the observed results. Instead, results are likely to indicate realistic potential outcomes for populations like the study community, as both models are designed to be plausible recreations of community life. Besides the dynamic vs. static contact networks, the largest difference between the two models is the lack of visiting in the SN model. However, the current format of visiting in the ABM raises major concerns. First, the level of visiting is a somewhat arbitrary value that may be too high, especially considering other behaviors are modeled as if the community was in the peak of the fishing season, and second, visiting occurs randomly among different households, with women and children most commonly engaging in this activity despite varying descriptions in the ethnographic and historical literature of informal social gatherings. While the SN model may overemphasize certain relationships and activities and does not allow for heterogeneity among particular pairs, it likely represents more realistic or common paths of transmission than agent pairs formed by visiting and other random contacts produced by the dynamic network.

The choice of model must be driven by research questions of interest and the availability of sufficient and reliable data. In this case, considering both the level of archival and ethnographic evidence for behaviors and kin or household relationships and the research goals of understanding differences in epidemic outcomes among demographic subgroups, the social network seems more informative and appropriate than the ABM. However, this model includes a complicated process of calculating link strengths based on assumptions of individual behavior in the ABM. These strengths must be calculated for every single pair of individuals based on their dwelling, household, and crew assignments, and the probability of different types of behaviors at different time intervals. Complex procedures are further required to change these strengths if adoption of orphaned children occurs during a simulated epidemic. Therefore, generalization or expansion of the SN model to other communities or diseases may prove difficult or impossible compared to the ABM. It is also important to note that, while differences between the models are often statistically significant, the absolute differences in both size and timing measures are frequently not particularly large. In a “real-world” practical or public health setting, these small differences may not be important enough to require the additional complexity of the SN model relative to the ABM.

Further Research

There are several main directions of future research that can be taken with this project. First, the study community formed part of a much larger region of relative economic and political importance. Models and analyses incorporating at least a few of the larger, better documented islands should be developed. Of particular interest would be determining whether the pattern of disease spread would be dominated by the larger population and institutions on the main island of Greenspond. This expansion could also allow for an integration or combination of modeling methods, such as agent-based models determining spread within islands and a social network model connecting the different islands together. Ultimately, it may be of interest to expand even beyond the immediate geographic region to explore variation among different communities in similar ecological contexts (e.g. St. Anthony, Newfoundland and Labrador, which was the model population in the original model from which this project's ABM model was derived, or other areas in Atlantic Canada or the northeastern United States with different political and economic histories).

The duration of simulations and number or types of diseases should also be expanded, particularly due to the important time period under consideration, i.e. just prior to the second epidemiological transition in this region. Syndemic analyses would provide more insight into the dynamics of infectious disease spread by taking into account multiple co-circulating pathogens and the effects of changing socioeconomic conditions or other factors. Similarly, demographic processes and how those affect social relationships, such as the breaking and forming of crews and households as the population ages, should be added to the model.

A third future direction for this research involves modifying both models to reflect more realistic behaviors (e.g. visiting, different levels of school attendance, or the inclusion of interactions among maternal kin), and to attempt to differentiate the outcomes produced by structural assumptions and the outcomes produced by assumptions reflecting community attributes and characteristics. For example, the SN model can be converted to a dynamic network model by allowing specific links to break or form during the progression of a simulation. For both models, additional behaviors and activities, such as participation in charitable or fraternal organizations, seasonal absences, and most importantly, disease-related behavior such as caring for ill family members, could be considered. As discussed above, the inclusion of specific details must be balanced with the need to keep models simple and generalizable. The goal of these models is not to reproduce the exact conditions and experience of the study community. Therefore, the decision to include any additional behaviors or features of daily life must be evaluated carefully.

This research suggests broader impacts for contemporary Newfoundlanders. Increased understanding into the health history of different parts of the island help explain how past events may have contributed to current social structure and family relationships. Further, consideration of the role of the ecological context and dependence on marine resources demonstrates how the patterns of living and the occupations available to residents can strongly influence health of individuals. Since Confederation with Canada and especially since a moratorium on cod fishing was implemented in the 1990s, economic and other factors have changed dramatically, including increased migration for employment and new or changing occupations (see, for example, Palmer, 2010; Schrank, 2005). Insights into how similar processes (e.g. seasonal migration to Labrador or the seal hunt, socioeconomic changes associated with the second epidemiological transition) affected disease spread may provide clues for what to expect in the future.

Additionally, findings from this research can be used to understand disease spread in communities outside of Newfoundland and Labrador. Many historical populations and even modern villages in rural or developing regions share similar characteristics of social organization. Data from the 1918 flu indicate these communities may be among the most severely affected by major epidemics, due in part to a lack of resources or infrastructure (e.g. Mamelund et al., 2013). Similarly, the 2014 Ebola epidemic illustrates the devastating local, regional and global effects that can emerge from disease outbreaks in small villages, and the need to develop appropriate interventions and responses to such events (e.g. Akhtar et al., 2014). Even in larger, urban areas, daily interactions and social relationships are likely most important or frequent among smaller subsets of the population based on residence and occupation. Recent studies focusing on larger factors influencing spread, such as global travel, might overlook the individual-level factors that affect epidemic outcomes within communities. Further, containment strategies during widespread epidemics or pandemics will likely be most effective if designed to target local hot spots of infection (Sattenspiel, 2009). This research demonstrates the importance of studying the system of disease spread at multiple levels.

Overall, this study provides insights both for understanding the effects of traditional activities and social organization on the spread of infectious disease epidemics and for selecting appropriate model designs for testing various hypotheses related to these kinds of research questions. At a broader level, this research also demonstrates the role such research can play in anthropological and epidemiological studies of population health. Frequently, disease-related research focuses on specific biological or cultural aspects that influence disease spread. This study contributes to a broader understanding of population health by investigating a combination of biocultural and ecological factors that contribute to the spread of disease among individuals within small communities.

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APPENDIX A – MODEL INPUT FILES

The three tables in this appendix are copies of the input files read into the models upon initialization. The construction of these files and how they are used in the models are described in more detail in Chapter 6 of this dissertation. Users who want to apply these models to different populations or contexts can create their own files following the format presented here. The files should be read in as tab-delimited .txt files without column headings in order to work with the Netlogo procedures.

Model Population File

This file contains values for 12 attributes for each agent or node in the model population. The attributes include ID, residence (all agents initialized with 1 for Newell's Island), disease status (all agents initialized as 0 or susceptible), dwelling, household, extended family, sex (0 for males, 1 for females), age (in years), church membership (values correspond to the building ID of the respective church), health history (all agents initialized with a neutral value of 0), occupation, and boat ID (values correspond to the building ID of the respective boat).

Table A.1. Input file with attributes for all agents in the model population

ID	Residence	Disease Status	Dwelling	Household	Ext. Family	Sex	Age	Church	Health History	Occ	Boat
1	1	0	1	1	2	0	71	25	0	301	101
2	1	0	1	1	2	1	67	25	0	201	101
3	1	0	2	2	2	0	42	25	0	101	101
4	1	0	2	2	2	1	40	25	0	201	101
5	1	0	2	2	2	0	18	25	0	101	101
6	1	0	2	2	2	1	13	25	0	801	101

7	1	0	2	2	2	1	10	25	0	801	101
8	1	0	3	3	2	0	48	25	0	101	101
9	1	0	3	3	2	1	47	25	0	201	101
10	1	0	4	4	2	0	29	25	0	102	102
11	1	0	4	4	2	1	26	25	0	702	102
12	1	0	4	4	2	0	6	25	0	802	102
13	1	0	4	4	2	0	4	25	0	902	102
14	1	0	4	4	2	1	2	25	0	902	102
15	1	0	4	4	2	1	0	25	0	902	102
16	1	0	5	5	1	0	24	26	0	103	103
17	1	0	5	5	1	1	22	26	0	703	103
18	1	0	5	5	1	1	1	26	0	903	103
19	1	0	6	6	1	0	29	25	0	103	103
20	1	0	6	6	1	1	28	25	0	703	103
21	1	0	6	6	1	1	6	25	0	803	103
22	1	0	6	6	1	0	4	25	0	903	103
23	1	0	6	6	1	0	2	25	0	903	103
24	1	0	7	7	1	0	48	26	0	104	104
25	1	0	7	7	1	1	43	26	0	704	104
26	1	0	7	7	1	0	16	26	0	104	104
27	1	0	7	7	1	1	14	26	0	804	104
28	1	0	7	7	1	1	12	26	0	804	104
29	1	0	7	7	1	0	10	26	0	804	104
30	1	0	7	7	1	0	8	26	0	804	104
31	1	0	7	7	1	0	4	26	0	904	104
32	1	0	7	7	1	1	1	26	0	904	104
33	1	0	8	8	1	0	54	26	0	105	105
34	1	0	8	8	1	1	47	26	0	205	105
35	1	0	8	8	1	0	26	26	0	105	105
36	1	0	8	8	1	1	23	26	0	205	105
37	1	0	8	8	1	0	22	26	0	105	105
38	1	0	8	8	1	0	19	26	0	105	105
39	1	0	8	8	1	0	15	26	0	805	105
40	1	0	9	9	1	0	67	26	0	104	104
41	1	0	9	9	1	1	65	26	0	204	104
42	1	0	9	10	1	0	26	26	0	104	104
43	1	0	9	10	1	1	23	26	0	704	104
44	1	0	9	10	1	1	0	26	0	904	104
45	1	0	10	11	2	0	65	25	0	101	101
46	1	0	10	11	2	1	65	25	0	201	101
47	1	0	10	11	2	1	14	25	0	801	101
48	1	0	11	12	1	0	62	25	0	103	103
49	1	0	11	12	1	1	63	25	0	203	103

50	1	0	11	13	1	0	48	25	0	103	103
51	1	0	12	14	3	0	58	25	0	106	106
52	1	0	12	14	3	1	56	25	0	206	106
53	1	0	12	14	3	0	26	25	0	106	106
54	1	0	12	14	3	0	20	25	0	106	106
55	1	0	12	14	3	1	16	25	0	206	106
56	1	0	13	15	3	0	36	25	0	106	106
57	1	0	13	15	3	1	36	25	0	706	106
58	1	0	13	15	3	0	12	25	0	806	106
59	1	0	13	15	3	0	7	25	0	806	106
60	1	0	13	15	3	0	0	25	0	906	106
61	1	0	14	16	4	0	66	25	0	106	106
62	1	0	15	17	2	1	56	25	0	202	102
63	1	0	15	17	2	0	20	25	0	102	102
64	1	0	15	17	2	0	17	25	0	102	102
65	1	0	16	18	1	0	40	25	0	103	103
66	1	0	16	18	1	1	41	25	0	703	103
67	1	0	16	18	1	1	19	25	0	303	103
68	1	0	16	18	1	0	15	25	0	803	103
69	1	0	16	18	1	1	12	25	0	803	103
70	1	0	16	18	1	0	9	25	0	803	103
71	1	0	16	18	1	0	2	25	0	903	103
72	1	0	17	19	5	0	56	26	0	107	107
73	1	0	17	19	5	1	52	26	0	707	107
74	1	0	17	19	5	0	31	26	0	107	107
75	1	0	17	19	5	0	7	26	0	807	107
76	1	0	17	19	5	0	4	26	0	907	107
77	1	0	17	19	5	1	2	26	0	907	107
78	1	0	17	19	5	0	28	26	0	107	107
79	1	0	17	19	5	0	27	26	0	407	107
80	1	0	17	19	5	0	19	26	0	107	107
81	1	0	17	19	5	0	18	26	0	107	107
82	1	0	17	19	5	1	13	26	0	807	107
83	1	0	18	20	5	0	25	26	0	107	107
84	1	0	18	20	5	1	21	26	0	707	107
85	1	0	18	20	5	0	0	26	0	907	107
86	1	0	19	21	1	0	51	25	0	108	108
87	1	0	19	21	1	1	52	25	0	208	108
88	1	0	19	21	1	0	20	25	0	108	108
89	1	0	19	21	1	1	16	25	0	208	108
90	1	0	19	21	1	0	14	25	0	808	108
91	1	0	19	21	1	0	12	25	0	808	108
92	1	0	19	22	1	0	24	25	0	108	108

93	1	0	19	22	1	1	25	25	0	708	108
94	1	0	19	22	1	1	2	25	0	908	108
95	1	0	20	23	1	0	25	25	0	108	108
96	1	0	20	23	1	1	23	25	0	708	108
97	1	0	20	23	1	0	2	25	0	908	108
98	1	0	20	23	1	1	1	25	0	908	108
99	1	0	21	24	1	0	56	26	0	109	109
100	1	0	21	24	1	1	56	26	0	209	109
101	1	0	21	24	1	0	36	26	0	109	109
102	1	0	21	25	1	0	25	26	0	109	109
103	1	0	21	25	1	1	23	26	0	709	109
104	1	0	21	25	1	1	0	26	0	909	109
105	1	0	21	24	1	1	22	26	0	209	109
106	1	0	21	24	1	0	19	26	0	109	109
107	1	0	21	24	1	1	17	26	0	209	109
108	1	0	21	24	1	1	15	26	0	809	109
109	1	0	21	24	1	0	11	26	0	809	109
110	1	0	22	26	1	0	62	25	0	109	109
111	1	0	22	26	1	1	61	25	0	209	109
112	1	0	23	27	2	0	26	25	0	102	102
113	1	0	23	27	2	1	25	25	0	702	102
114	1	0	23	27	2	0	1	25	0	902	102

Buildings File

This file contains information about the buildings used in the visualization of the agent-based model. All buildings are modeled as rectangular clusters of cells, and each cell is assigned the same building ID and type. The input variables include the x-coordinate and y- coordinate for the lower left cell, the building width and length measured in number of cells, the building ID, and the building type. Building types include houses (1), schools (2), churches (3), and boats (4 and 5, assigned different numerical values so alternating boats can be given different colors in the visualization).

Table A.2. Input file with attributes for all buildings in the ABM

X-Coordinate	Y-Coordinate	Width	Length	ID	Type
4	39	4	4	1	1
11	90	4	4	2	1
12	10	4	4	3	1
14	55	4	4	4	1
20	37	4	4	5	1
20	75	4	4	6	1
25	21	4	4	7	1
27	63	4	4	8	1
34	93	4	4	9	1
39	53	4	4	10	1
45	22	4	4	11	1
46	41	4	4	12	1
50	80	4	4	13	1
53	4	4	4	14	1
71	72	4	4	15	1
72	36	4	4	16	1
72	86	4	4	17	1
73	15	4	4	18	1
77	51	4	4	19	1
83	27	4	4	20	1
84	6	4	4	21	1
84	65	4	4	22	1
85	93	4	4	23	1
58	26	7	5	24	2
26	5	6	11	25	3
52	64	7	7	26	3
97	30	3	4	101	4
97	34	3	4	102	5
97	38	3	4	103	4
97	42	3	4	104	5
97	46	3	4	105	4
97	50	3	4	106	5
97	54	3	4	107	4
97	58	3	4	108	5
97	62	3	4	109	4

Links File

The table presented here is an abridged version of the input text file used to read in information about links between nodes in the social network model. The full file contains details for each of the links among all pairs of nodes in the social network model. The variables read into the model include the ID of the node originating the link (referred to as node A in the table below), the ID of the node terminating the link (node B), the strength of the link between the node pair, and an affinity code value. Affinity codes are currently not used and are designed for future extensions. These codes will increase heterogeneity in the model by allowing for small strength adjustments to the links between different types of node pairs, such as schoolchildren of different age groups to indicate closer friendships than the baseline strength. All links are currently assigned an affinity code of 0 and therefore are not included in the table presented here. Further, all possible links between all possible nodes need to be read into the model code, even if the assigned strength is 0. However, in the interest of conserving space, only links with a strength greater than 0 are included in the table below.

Table A.3. Abridged input file with attributes for links between node pairs in the SN model

ID of Node A	ID of Node B	Link Strength	ID of Node A	ID of Node B	Link Strength	ID of Node A	ID of Node B	Link Strength
1	2	0.116	27	32	0.112	67	108	0.035
1	6	0.035	27	39	0.035	67	109	0.035
1	7	0.035	27	40	0.015	68	69	0.157
1	12	0.035	27	41	0.008	68	70	0.147
1	21	0.035	27	42	0.015	68	71	0.112
1	27	0.035	27	47	0.035	68	75	0.035
1	28	0.035	27	58	0.035	68	82	0.035
1	29	0.035	27	59	0.035	68	90	0.035

1	30	0.035	27	67	0.035	68	91	0.035
1	39	0.035	27	68	0.035	68	108	0.035
1	47	0.035	27	69	0.035	68	109	0.035
1	58	0.035	27	70	0.035	69	70	0.147
1	59	0.035	27	75	0.035	69	71	0.112
1	67	0.035	27	82	0.035	69	75	0.035
1	68	0.035	27	90	0.035	69	82	0.035
1	69	0.035	27	91	0.035	69	90	0.035
1	70	0.035	27	108	0.035	69	91	0.035
1	75	0.035	27	109	0.035	69	108	0.035
1	82	0.035	28	29	0.157	69	109	0.035
1	90	0.035	28	30	0.147	70	71	0.12
1	91	0.035	28	31	0.112	70	75	0.036
1	108	0.035	28	32	0.112	70	82	0.035
1	109	0.035	28	39	0.035	70	90	0.035
2	3	0.059	28	40	0.015	70	91	0.035
2	4	0.047	28	41	0.008	70	108	0.035
2	5	0.059	28	42	0.015	70	109	0.035
2	6	0.008	28	47	0.035	72	73	0.11
2	7	0.008	28	58	0.035	72	74	0.22
2	8	0.059	28	59	0.035	72	75	0.11
2	9	0.047	28	67	0.035	72	76	0.11
2	45	0.059	28	68	0.035	72	77	0.11
2	46	0.047	28	69	0.035	72	78	0.22
2	47	0.008	28	70	0.035	72	79	0.11
3	4	0.168	28	75	0.035	72	80	0.22
3	5	0.22	28	82	0.035	72	81	0.22
3	6	0.124	28	90	0.035	72	82	0.124
3	7	0.124	28	91	0.035	72	83	0.11
3	8	0.11	28	108	0.035	73	74	0.11
3	9	0.059	28	109	0.035	73	75	0.12
3	45	0.11	29	30	0.147	73	76	0.195
3	46	0.059	29	31	0.112	73	77	0.195
3	47	0.015	29	32	0.112	73	78	0.11
4	5	0.168	29	39	0.035	73	79	0.11
4	6	0.119	29	40	0.015	73	80	0.11
4	7	0.119	29	41	0.008	73	81	0.11
4	8	0.059	29	42	0.015	73	82	0.112
4	9	0.047	29	47	0.035	74	75	0.11
4	45	0.059	29	58	0.035	74	76	0.11
4	46	0.047	29	59	0.035	74	77	0.11
4	47	0.008	29	67	0.035	74	78	0.22
5	6	0.124	29	68	0.035	74	79	0.11

5	7	0.124	29	69	0.035	74	80	0.22
5	8	0.11	29	70	0.035	74	81	0.22
5	9	0.059	29	75	0.035	74	82	0.124
5	45	0.11	29	82	0.035	74	83	0.11
5	46	0.059	29	90	0.035	75	76	0.12
5	47	0.015	29	91	0.035	75	77	0.12
6	7	0.157	29	108	0.035	75	78	0.11
6	8	0.015	29	109	0.035	75	79	0.11
6	9	0.008	30	31	0.12	75	80	0.11
6	12	0.035	30	32	0.12	75	81	0.11
6	21	0.035	30	39	0.035	75	82	0.147
6	27	0.035	30	47	0.035	75	90	0.035
6	28	0.035	30	58	0.035	75	91	0.035
6	29	0.035	30	59	0.036	75	108	0.035
6	30	0.035	30	67	0.035	75	109	0.035
6	39	0.035	30	68	0.035	76	77	0.195
6	45	0.015	30	69	0.035	76	78	0.11
6	46	0.008	30	70	0.036	76	79	0.11
6	47	0.047	30	75	0.036	76	80	0.11
6	58	0.035	30	82	0.035	76	81	0.11
6	59	0.035	30	90	0.035	76	82	0.112
6	67	0.035	30	91	0.035	77	78	0.11
6	68	0.035	30	108	0.035	77	79	0.11
6	69	0.035	30	109	0.035	77	80	0.11
6	70	0.035	31	32	0.195	77	81	0.11
6	75	0.035	33	34	0.168	77	82	0.112
6	82	0.035	33	35	0.22	78	79	0.11
6	90	0.035	33	36	0.168	78	80	0.22
6	91	0.035	33	37	0.22	78	81	0.22
6	108	0.035	33	38	0.22	78	82	0.124
6	109	0.035	33	39	0.124	78	83	0.11
7	8	0.015	34	35	0.168	79	80	0.11
7	9	0.008	34	36	0.187	79	81	0.11
7	12	0.035	34	37	0.168	79	82	0.11
7	21	0.035	34	38	0.168	80	81	0.22
7	27	0.035	34	39	0.119	80	82	0.124
7	28	0.035	35	36	0.168	80	83	0.11
7	29	0.035	35	37	0.22	81	82	0.124
7	30	0.035	35	38	0.22	81	83	0.11
7	39	0.035	35	39	0.124	82	83	0.015
7	45	0.015	36	37	0.168	82	90	0.035
7	46	0.008	36	38	0.168	82	91	0.035
7	47	0.047	36	39	0.119	82	108	0.035

7	58	0.035	37	38	0.22	82	109	0.035
7	59	0.035	37	39	0.124	83	84	0.11
7	67	0.035	38	39	0.124	83	85	0.11
7	68	0.035	39	47	0.035	84	85	0.195
7	69	0.035	39	58	0.035	86	87	0.168
7	70	0.035	39	59	0.035	86	88	0.22
7	75	0.035	39	67	0.035	86	89	0.168
7	82	0.035	39	68	0.035	86	90	0.124
7	90	0.035	39	69	0.035	86	91	0.124
7	91	0.035	39	70	0.035	86	92	0.216
7	108	0.035	39	75	0.035	86	93	0.106
7	109	0.035	39	82	0.035	86	94	0.106
8	9	0.168	39	90	0.035	86	95	0.11
8	45	0.11	39	91	0.035	87	88	0.168
8	46	0.059	39	108	0.035	87	89	0.187
8	47	0.015	39	109	0.035	87	90	0.119
9	45	0.059	40	41	0.168	87	91	0.119
9	46	0.047	40	42	0.216	87	92	0.165
9	47	0.008	40	43	0.106	87	93	0.143
10	11	0.11	40	44	0.106	87	94	0.143
10	12	0.11	41	42	0.165	87	95	0.059
10	13	0.11	41	43	0.143	88	89	0.168
10	14	0.11	41	44	0.143	88	90	0.124
10	15	0.11	42	43	0.11	88	91	0.124
10	45	0.11	42	44	0.11	88	92	0.216
10	46	0.059	43	44	0.195	88	93	0.106
10	47	0.015	45	46	0.168	88	94	0.106
10	62	0.059	45	47	0.124	88	95	0.11
10	63	0.11	46	47	0.119	89	90	0.119
10	64	0.11	47	58	0.035	89	91	0.119
10	112	0.11	47	59	0.035	89	92	0.165
11	12	0.12	47	67	0.035	89	93	0.143
11	13	0.195	47	68	0.035	89	94	0.143
11	14	0.195	47	69	0.035	89	95	0.059
11	15	0.195	47	70	0.035	90	91	0.157
12	13	0.12	47	75	0.035	90	92	0.121
12	14	0.12	47	82	0.035	90	93	0.108
12	15	0.12	47	90	0.035	90	94	0.108
12	21	0.036	47	91	0.035	90	95	0.015
12	27	0.035	47	108	0.035	90	108	0.035
12	28	0.035	47	109	0.035	90	109	0.035
12	29	0.035	48	49	0.168	91	92	0.121
12	30	0.036	48	50	0.216	91	93	0.108

12	39	0.035	48	65	0.11	91	94	0.108
12	47	0.035	48	68	0.015	91	95	0.015
12	58	0.035	48	69	0.015	91	108	0.035
12	59	0.036	49	50	0.165	91	109	0.035
12	67	0.035	49	65	0.059	92	93	0.11
12	68	0.035	49	68	0.008	92	94	0.11
12	69	0.035	49	69	0.008	92	95	0.11
12	70	0.036	50	65	0.11	93	94	0.195
12	75	0.036	50	68	0.015	95	96	0.11
12	82	0.035	50	69	0.015	95	97	0.11
12	90	0.035	51	52	0.168	95	98	0.11
12	91	0.035	51	53	0.22	96	97	0.195
12	108	0.035	51	54	0.22	96	98	0.195
12	109	0.035	51	55	0.168	97	98	0.195
13	14	0.195	51	56	0.11	99	100	0.168
13	15	0.195	51	58	0.015	99	101	0.22
14	15	0.195	51	61	0.11	99	102	0.216
16	17	0.11	52	53	0.168	99	103	0.106
16	18	0.11	52	54	0.168	99	104	0.106
16	19	0.11	52	55	0.187	99	105	0.168
16	48	0.11	52	56	0.059	99	106	0.22
16	49	0.059	52	58	0.008	99	107	0.168
16	50	0.11	52	61	0.059	99	108	0.124
16	65	0.11	53	54	0.22	99	109	0.124
16	68	0.015	53	55	0.168	99	110	0.11
16	69	0.015	53	56	0.11	99	111	0.059
17	18	0.195	53	58	0.015	100	101	0.168
19	20	0.11	53	61	0.11	100	102	0.165
19	21	0.11	54	55	0.168	100	103	0.143
19	22	0.11	54	56	0.11	100	104	0.143
19	23	0.11	54	58	0.015	100	105	0.187
19	48	0.11	54	61	0.11	100	106	0.168
19	49	0.059	55	56	0.059	100	107	0.187
19	50	0.11	55	58	0.008	100	108	0.119
19	65	0.11	55	61	0.059	100	109	0.119
19	68	0.015	56	57	0.11	100	110	0.059
19	69	0.015	56	58	0.124	100	111	0.047
20	21	0.12	56	59	0.11	101	102	0.216
20	22	0.195	56	60	0.11	101	103	0.106
20	23	0.195	56	61	0.11	101	104	0.106
21	22	0.12	57	58	0.112	101	105	0.168
21	23	0.12	57	59	0.12	101	106	0.22
21	27	0.035	57	60	0.195	101	107	0.168

21	28	0.035	58	59	0.147	101	108	0.124
21	29	0.035	58	60	0.112	101	109	0.124
21	30	0.036	58	61	0.015	101	110	0.11
21	39	0.035	58	67	0.035	101	111	0.059
21	47	0.035	58	68	0.035	102	103	0.11
21	58	0.035	58	69	0.035	102	104	0.11
21	59	0.036	58	70	0.035	102	105	0.165
21	67	0.035	58	75	0.035	102	106	0.216
21	68	0.035	58	82	0.035	102	107	0.165
21	69	0.035	58	90	0.035	102	108	0.121
21	70	0.036	58	91	0.035	102	109	0.121
21	75	0.036	58	108	0.035	102	110	0.11
21	82	0.035	58	109	0.035	102	111	0.059
21	90	0.035	59	60	0.12	103	104	0.195
21	91	0.035	59	67	0.035	103	105	0.143
21	108	0.035	59	68	0.035	103	106	0.106
21	109	0.035	59	69	0.035	103	107	0.143
22	23	0.195	59	70	0.036	103	108	0.108
24	25	0.11	59	75	0.036	103	109	0.108
24	26	0.22	59	82	0.035	104	105	0.143
24	27	0.124	59	90	0.035	104	106	0.106
24	28	0.124	59	91	0.035	104	107	0.143
24	29	0.124	59	108	0.035	104	108	0.108
24	30	0.11	59	109	0.035	104	109	0.108
24	31	0.11	62	63	0.168	105	106	0.168
24	32	0.11	62	64	0.168	105	107	0.187
24	40	0.11	62	112	0.059	105	108	0.119
24	41	0.059	63	64	0.22	105	109	0.119
24	42	0.11	63	112	0.11	105	110	0.059
25	26	0.11	64	112	0.11	105	111	0.047
25	27	0.112	65	66	0.11	106	107	0.168
25	28	0.112	65	67	0.11	106	108	0.124
25	29	0.112	65	68	0.124	106	109	0.124
25	30	0.12	65	69	0.124	106	110	0.11
25	31	0.195	65	70	0.11	106	111	0.059
25	32	0.195	65	71	0.11	107	108	0.119
26	27	0.124	66	67	0.12	107	109	0.119
26	28	0.124	66	68	0.112	107	110	0.059
26	29	0.124	66	69	0.112	107	111	0.047
26	30	0.11	66	70	0.12	108	109	0.157
26	31	0.11	66	71	0.195	108	110	0.015
26	32	0.11	67	68	0.146	108	111	0.008
26	40	0.11	67	69	0.146	109	110	0.015

26	41	0.059	67	70	0.154	109	111	0.008
26	42	0.11	67	71	0.12	110	111	0.168
27	28	0.157	67	75	0.035	112	113	0.11
27	29	0.157	67	82	0.035	112	114	0.11
27	30	0.147	67	90	0.035	113	114	0.195
27	31	0.112	67	91	0.035			

APPENDIX B – MODEL CODE

This appendix contains the model code for both the agent-based and social network models. Both were written in the open-access modeling platform Netlogo, which uses a programming language similar to Java. To implement the models, two input files are required: an agents file that lists characteristics of all members of the model population (both models) and either a building file that lists the types, sizes and locations of the buildings (agent-based model only), or a links file that lists the strengths of relationships between individual pairs of nodes (social network model only). The specific files used in this project are provided in Appendix A. Please note that the sections of the code below for reading in text files and setting up the network layout were modified from code submitted to Netlogo's model library by Uri Wilensky, who has waived all copyright and related rights to the sample code.

Agent-Based Model Code

```
;;Variable Declarations

globals [
  ;; Slider variables. Baseline values listed below are standard values to use if not exploring the effect of the particular variable. Estimates are derived from literature or Newfoundland data for the 1918 influenza pandemic.
  ;latent-period  ; baseline value = 1 day or 6 ticks (literature).
  ;infectious-period  ; baseline value = 3 days or 18 ticks (literature).
  ;transmission-prob ; baseline value = 0.045 (estimated to achieve a target 30% attack rate, as observed in Greenspond mortality data)
  ;death-prob ; baseline value = 0.0013 per tick which converts to about 7.3 deaths per 1000  over the course of an epidemic (estimated from Greenspond mortality data)
  ;church-density; default value = 1.0. Sets percent level allowed to attend church service. Both churches are assumed to use the same density.
  ;run-length; default value = 400. The number of ticks a simulation should run

  pop-size ; This variable is used for data recording purposes only and is set equal to the count of agents at the start of a simulation
  num-susceptible num-exposed num-infectious num-recovered num-dead
```

```
  num-orphans-gone ; The number of orphans who can't find a caretaker and are adopted out of the
community
  num-infected-orphans-gone ; The number of orphans who are exposed, infectious or recovered when
they leave the community. These children are recorded because they are essentially still part of the
community's epidemic
  RD RDNsO SRDO ; values used for keeping tallies for data-recording. RD = recovered + dead (size of
epidemic excluding orphans who have left the community), RDNsO = RD + non-susceptible orphans (size
of epidemic including orphans who have left the community), SRDO= susceptible + RD + all orphans
regardless of disease status (confirms that the epidemic has concluded, should equal pop-size)

  first-case ; the agt-id of the first infected case
  first-case-occ ; the occupation of the first infected case

  church1-id ; The following two variables are the building-ids of the different churches; these variables
are initialized in import-map-data
  church2-id
  num-houses num-schools num-churches num-boats
  house-list

  timekeeper ; determines the simulation's current 4-hour time block so agents call the appropriate
activity methods, include this information in print statements, etc. Timekeeper values of 1-6 correspond
to blocks on Mon-Fri(6a10a, 10a2p, 2p6p, 6p10p, 10p2a, 2a-6a), 7-12 correspond to the same time
intervals on Saturdays, 13-18 correspond to Sundays.
]

breed [NI-agents NI-agent]
breed [ghosts ghost]
breed [orphans orphan]

turtles-own [ ; The first 12 variables are read in from a file
  agt-id
  residence  ; All agents are set to 1 which corresponds to Newell's Island.
  disease-status ; 0 = susceptible, 1 = exposed, 2 = infectious, 3 = recovered, 4 = dead
  dwelling ; The ID of a person's dwelling
  household ; The ID of a person's household. Multiple households per dwelling are possible.
  ext-family ; The ID of a person's extended family, currently used in adoption methods only. The values
correspond to surnames listed in the 1911 census.
  sex ; male = 0, female = 1
  age
  church ; The present model includes two churches. This variable indicates which of these an agent
attends.
  health-history ; Corresponds to an agent's relative health status, designed to take into account different
possible influences that may impact an agent's outcome when faced with a potential disease-transmitting
contact. This variable can range from -1 to 1, with -1 corresponding to a maximum negative impact (i.e.,
100% reduction), 0 corresponding to no impact on health, and 1 corresponding to a maximum positive
impact. All agents are currently set to 0 because this variable is designed for future model versions.
  occupation ; is a user-defined integer variable corresponding to an agent's occupation. All agents have
been assigned a 3-digit occupation code. See the Info tab for more details on these specific occupation
codes. Occupations refer to agent behavior categories that relate to normal daily activities.
  boat-id ; all agents in regular households are assigned to the associated boat-id, even if their
occupational activities do not include fishing. Any exceptions should be assigned a default value of 999.
```

```
  occ-type ; A single digit code referring to the agent's general occupation category and corresponding to the first digit of the occupation value, e.g. 1 = fishermen, whereas an occupation of 102 = a fisherman assigned to boat 102.

  present-location ; the building-id of the patch where an agent is currently located
  can-visit? ; boolean checks whether an agent is allowed to visit other dwellings
  family-can-move? ; boolean checks whether a family is free to visit on Sundays
  group-size ; the number of individuals moving together in a traveling group
  destx ; These two variables are the x,y coordinates of the desired destination patch when agents move to a new location
  desty
  temp-dwelling ; The ID of a building an agent will temporarily visit if it can't find a place at home

  ; The following variables are used to identify males in occ-types 1 (fishermen) and 3 (teachers/clergy) who also are the "primary" caretaker for children in their household.
  fisherman-caretaker? ; a fisherman who is a caretaker of school-aged children only.
  stay-at-home-dad? ; a fisherman who is a caretaker of at least one preschool-aged child.
  teacher-caretaker? ; a pastor/teacher who is a caretaker of school-aged children only.

  ; The following variables are used during the adoption process upon the death of the child(ren)'s previous caretaker.
  children-under-five? ; True if there are any preschool children living in the household
  ; The following 3 booleans are set true if the desired caretaker has been identified
  sameHH-caretaker-found? ; Same household as the previous caretaker
  sameDW-caretaker-found? ; Same dwelling/different household as the previous caretaker
  extfam-caretaker-found? ; Same extended family/different dwelling as the previous caretaker
  any-caretaker-found? ; Any suitable adult in the community
  new-caretaker ; the agent (turtle object) selected to be the new caretaker

  time-to-infectious ; Timer variable set equivalent to the latent period that starts running at the tick an agent is infected
  time-to-recovery ; Timer variable set equivalent to the infectious period that starts running at the tick an infected agent becomes infectious
  time-infected ; Tick at which the agent is infected
  place-infected ; building-id of location where an agent is infected
  time-leaves-village ; timer variable to indicate the tick at which a child is unable to find a caretaker and is adopted out of the community
  time-died
  place-died
  infector-id ; the agt-id of the infecting agent
  infector-occ ; the occupation of the infecting agent
  infector-dwelling ; the building-ID of the infecting agent's dwelling

  newly-infected?
  newly-infectious?
  newly-dead?
  step-completed?
  ]

NI-agents-own [
  possible-new-cases
  possible-infectors
]
```

```
patches-own [
  occupied? ; checks whether a patch is occupied by an agent.
  building-id ; id of the building located on the patch
  building-type ; 1 = house, 2 = school, 3 = church, 4/5 = boat (alternate colors for visualization purposes)
]

;;Setup Methods

to setup
  clear-all
  ask patches [
    set pcolor gray + 4
    set occupied? false
    set building-id 0]
  import-map-data
  import-agent-data
  initialize-globals
  infect-first-case

  create-files
  reset-ticks
end


; This procedure creates the buildings on the NI map by reading in a file that contains the coordinates of
the lower left-hand corner (x, then y), the dimensions of the building (width, then length), the building-id
and the building type for each building. The method then counts the number of buildings of each type and
makes a list of the building-ids for all houses. It then identifies the remaining cells in the building and
ensures they have the same building-id and type. At the end of the procedure, all patches are given
pcolors corresponding to their building type; those patches that are not buildings retain the base gray
color.

to import-map-data
  set house-list []
  file-open "NIBldgs114Final.txt"
  while [not file-at-end?]
  [
    ; The following code reads a single line into a six-item list and uses the information in the list to create
the buildings
    let items read-from-string (word "[" file-read-line "]") ; Items is a temporary list of variables read in as
string but converted to the appropriate variable type. "Word" concatenates the brackets to the line being
read in, because list arguments need to be in brackets (see Netlogo user manual)

    let llc-x item 0 items
    let llc-y item 1 items
    let building-width item 2 items
    let building-length item 3 items

    ask patch llc-x llc-y [
      set building-id item 4 items
      set building-type item 5 items
```

```
   if building-type = 1 [
    set num-houses num-houses + 1
    set house-list lput building-id house-list] ; House
   if building-type = 2 [set num-schools num-schools + 1] ; School
   if building-type = 3 [set num-churches num-churches + 1] ; Church
   if building-type = 4 [set num-boats num-boats + 1] ; Boat type "A" - The boats are assigned alternating colors to differentiate adjacent boats on the map
   if building-type = 5 [set num-boats num-boats + 1] ; Boat type "B" - The boats are assigned alternating colors to differentiate adjacent boats on the map
   ]

  ;The following lines of code finds all patches in a building and sets each patch's ID and type to match the values assigned to the lower left corner
  let building-patches (patch-set patches with [pxcor >= llc-x and pxcor < llc-x + building-width and pycor >= llc-y and pycor < llc-y + building-length])
  ask building-patches [
   set building-id [building-id] of patch llc-x llc-y
   set building-type [building-type] of patch llc-x llc-y]

  ask patches [
   set occupied? false ;
   if building-type = 1 [set pcolor green] ; House
   if building-type = 2 [set pcolor red + 2] ; School
   if building-type = 3 [set pcolor violet + 3] ; Church
   if building-type = 4 [set pcolor cyan] ; Boat type "A" - The boats are assigned alternating colors to differentiate adjacent boats on the map
   if building-type = 5 [set pcolor sky] ; Boat type "B" - The boats are assigned alternating colors to differentiate adjacent boats on the map
   ]
  ]
 file-close

 set church1-id 25
 set church2-id 26
end

; This procedure creates the agents and assigns their attributes by reading in a file that contains the 12 agent-specific attributes listed above as turtles-own variables and indicated as input from file. It also sets the initial values of the additional turtles-own variables that are not read in.
to import-agent-data
 file-open "NIAgents114Final.txt"
 ; The following code reads in all the data in the file. Each line of data contains the values for the first 12 attributes for a single agent in the order listed below.
 while [not file-at-end?]
 [
  let items read-from-string (word "[" file-read-line "]") ; Items is a temporary list of variables read in as string but converted to the appropriate variable type. "Word" concatenates the brackets to the line being read in, because list arguments need to be in brackets (see Netlogo user manual)
  create-NI-agents 1 [
   set agt-id item 0 items
   set residence item 1 items
   set disease-status item 2 items
   set dwelling item 3 items
```

```
     set household item 4 items
     set ext-family item 5 items
     set sex item 6 items
     set age item 7 items
     set church item 8 items
     set health-history item 9 items
     set occupation item 10 items
     set boat-id item 11 items

     set occ-type floor (occupation / 100)  ;floor reports the largest integer less than or equal to input
number

     set present-location 0
     set can-visit? true
     set family-can-move? true
     set group-size 1

     set children-under-five? false
     set fisherman-caretaker? false
     set stay-at-home-dad? false
     set teacher-caretaker? false

     set sameHH-caretaker-found? false
     set sameDW-caretaker-found? false
     set extfam-caretaker-found? false
     set any-caretaker-found? false
     set new-caretaker nobody

     set time-to-infectious latent-period
     set time-to-recovery infectious-period
     set time-infected -1
     set place-infected -1
     set time-leaves-village -1
     set time-died -1
     set place-died -1
     set infector-id -1
     set infector-occ -1
     set infector-dwelling -1

     set newly-infected? false
     set newly-infectious? false
     set newly-dead? false
     set step-completed? false

     set shape "circle"
     set color black
     set size 1
   ]
  ]
  file-close

  ask turtles [initialize-home]
end
```

```
to initialize-home
    let home-patches (patch-set patches with [building-id = [dwelling] of myself and not occupied?])
    ifelse any? home-patches
      [let dest-patch one-of home-patches
       assign-location (dest-patch)
      ] ; closes if of any? home-patches
      [reassign-dwelling] ; close else of any? home-patches. If there are no unoccupied patches in the
agent's assigned dwelling, it needs to find a new place to live.
end

to reassign-dwelling  ; Agents find a random, empty dwelling patch and moves to the dwelling associated
with it. The agent then changes all relevant variables reflecting its new permanent dwelling assignment.
Future versions of this model may consider prioritizing the selection process so agents first select a
household with same extfamily.
  let open-home-patches (patch-set patches with [building-type = 1 and not occupied?])
  set dwelling [building-id] of one-of open-home-patches
  let other-residents (turtle-set NI-agents with [dwelling = [dwelling] of myself])
  let new-housemate one-of other-residents
  set household [household] of new-housemate
  set church [church] of new-housemate
  set boat-id [boat-id] of new-housemate
  let occ-part remainder boat-id 100
  set occupation occ-type * 100 + occ-part
  let new-home-patches (patch-set patches with [building-id = [dwelling] of myself and not occupied?])
  let new-home one-of new-home-patches
  assign-location (new-home)
end

to initialize-globals
  set pop-size count NI-agents
  set num-susceptible count NI-agents
  set num-infectious 0
  set num-recovered 0
  set num-dead 0
  set num-orphans-gone 0
  set num-infected-orphans-gone 0
  set RD 0
  set RDNsO 0
  set SRDO 0

  set first-case 0
  set first-case-occ 0

  set timekeeper 0
end

to infect-first-case ; This method should be used when the epidemic starts at time 0. If a user wants to
delay the start of the epidemic, the call for this method should be removed from setup and moved to the
desired place in the go method, and values of relevant variables, particularly time-infected, should be set
accordingly ("ticks").
  ask one-of NI-agents [  ; Randomly chooses one NI-agent to be the first case.
```

```
  ;  ask turtle 3 [ ; Chooses a specific turtle to be the first case. If a random agent with specific
characteristics is desired, the code can be changed accordingly. NOTE: when using "ask turtle X," the
agent must be identified by its who value, which is the agt-id - 1
    set disease-status 1 ; "Exposed"
    set num-exposed 1
    set num-susceptible num-susceptible - 1
    set color yellow + 2
    set time-to-infectious latent-period

    ; The indicated values for the following variables allow the user to easily identify the first case in output
data
    set time-infected 0
    set place-infected [building-id] of patch-here
    set infector-id 0
    set infector-occ 0
    set infector-dwelling 0
    set first-case agt-id
    set first-case-occ occupation
;    type "Run: " type behaviorspace-run-number type ", Agent: " type agt-id print " is the first case"
   ]
end

to create-files

  ; The next three blocks of code put headers at the top of new output files (one each for case, daily and
final data) and then the files are closed again, which must happen before a simulation begins. The process
of inserting headers only happens if the files don't exist already. If a file does exist, output data are just
appended to data from previous simulations without inserting headers again.

  if (not file-exists? "CasesData.csv")[
  file-open "CasesData.csv"
  file-type "Run Number,"
  file-type "Tick, "
  file-type "Population Size, "
  file-type "Transmission Probability, "
  file-type "Mortality Probability, "
  file-type "Latent Period, "
  file-type "Infectious Period, "
  file-type "First Case ID, "
  file-type "First Case Occ, "
  file-type "Agent ID, "
  file-type "Agent Dwelling, "
  file-type "Agent Occupation, "
  file-type "Infector ID, "
  file-type "Infector Dwelling, "
  file-type "Infector Occupation, "
  file-type "Time Infected, "
  file-type "Place Infected, "
  file-type "Time Died, "
  file-type "Place Died, "
  file-print "Time Leaves Village, "
  file-close]
```

```
  if (not file-exists? "DailyData.csv")[
  file-open "DailyData.csv"
  file-type "Run Number,"
  file-type "Tick, "
  file-type "Population Size, "
  file-type "Transmission Probability, "
  file-type "Mortality Probability, "
  file-type "Latent Period, "
  file-type "Infectious Period, "
  file-type "First Case ID, "
  file-type "First Case Occ, "
  file-type "Susceptible, "
  file-type "Newly Infected, "
  file-type "Exposed, "
  file-type "Infectious, "
  file-type "Recovered, "
  file-type "Newly Dead, "
  file-type "Total Dead, "
  file-type "Non-Susceptible Orphan Migrants, "
  file-print "Total Orphan Migrants, "
  file-close]

  if (not file-exists? "FinalData.csv")[
  file-open "FinalData.csv"
  file-type "Run Number,"
  file-type "Tick, "
  file-type "Population Size, "
  file-type "Transmission Probability, "
  file-type "Mortality Probability, "
  file-type "Latent Period, "
  file-type "Infectious Period, "
  file-type "First Case ID, "
  file-type "First Case Occ, "
  file-type "Susceptible, "
  file-type "Recovered, "
  file-type "Total Dead, "
  file-type "Non-Susceptible Orphan Migrants, "
  file-type "Total Orphan Migrants, "
  file-type "R+D (Final Size/No Orphans), "
  file-type "R+D+NsO (Final Size/Orphans), "
  file-print "S+R+D+O (Finish?), "
  file-close]
end

;;Step Methods

to go
  ask turtles[  ; the newly? variables reset here are for data recording purposes and to prevent multiple transmissions (e.g. if an agent is infected by another before it goes through the go method itself and before disease variables are updated accordingly).
    if time-infected != ticks + 1[
    set newly-infected? false]
  set newly-dead? false]
```

```
 ask one-of turtles [set-timekeeper]

 ask NI-agents [
  if (disease-status = 1 or disease-status = 2) [update-disease-status]

  if disease-status != 4 [
   find-days-activities

  ; The following code first makes a turtle set of the von Neumann neighbors of the calling agent, i.e. the
4 cells to the NSWE. This model considers this neighborhood, rather than the Moore neighborhood, which
includes diagonal cells. The Moore neighborhood, with its 8 neighbors, causes disease transmission to be
unrealistically rapid. Consideration of this process suggests that a limit of four contacts at a time reflects
how many individuals people interact with simultaneously, even in relatively crowded situations. The
method then makes a subset of the neighbor-agents appropriate for transmission. If the agent is
susceptible, then the method makes a subset of the neighbor-agents who are infectious and vice versa.

   let neighbor-agents (turtle-set NI-agents-on neighbors4)
   ifelse disease-status = 0
    [if any? neighbor-agents with [disease-status = 2] [
      set possible-infectors neighbor-agents with [disease-status = 2]
      transmit-from (possible-infectors)]] ; called by a susceptible agent
    [if disease-status = 2 [
      if any? neighbor-agents with [disease-status = 0] [
       set possible-new-cases neighbor-agents with [disease-status = 0]
       transmit-to (possible-new-cases)]] ; called by an infectious agent
     ] ; closes else of disease status = 0
   ] ; closes if dis-status != 4

  set step-completed? true
 ] ; closes ask NI-agents

 ask ghosts [  ; Immediately after SA-agents die, any caretakers must arrange for dependent children to be
reassigned to new caretakers. Any dying children need to determine whether they have surviving siblings
under age 5 and if not, arrange for male caretakers to return to previous activities, e.g. fishing. Female
caretakers retain their existing status throughout the rest of the simulation.  Dying agents who are
engaged in critical occupations, e.g. pastors/teachers, etc. are also replaced by suitable living agents.
  if newly-dead? [reassign-occupation]
 ]

 ; Turtles must reset this boolean for the next iteration through the go method.
 ask turtles [
  set step-completed? false
  set newly-infectious? false] ; This value may change to true when update-disease-status is called above.
It is a check that allows infectious agents to survive and transmit at least one tick before dying

 update-daily-output

 ; The tick value (on the run-length slider) can and should be set with the appropriate parameter value to
make sure the entire epidemic is included in data output
 if ticks + 1 = run-length [
  update-final-output
  stop]
```

```
  tick ; Increments the tick value
end

; The program is being set up for six time ticks per day. Consequently, each time tick is 4 hours long. The
series of if statements sets up a time schedule within which agent activities will occur. A day is divided
into 6 time slots, i.e. 6-10 AM 10 AM-2 PM, 2-6 PM, 6-10 PM, 10 PM-2 AM and 2-6AM. Values of
timekeeper between 1 and 6 correspond to these six slots on Mondays through Friday (in this order).
Values between 7 and 12 correspond to the six slots on Saturdays.  Values between 13 and 18 correspond
to these six slots on Sundays.
to set-timekeeper
  let counter ticks + 1
  if (remainder (counter - 1) 6 = 0) and (remainder (counter - 31) 42 != 0) and (remainder (counter - 37) 42
!= 0) [set timekeeper 1]
  if (remainder (counter - 2) 6 = 0) and (remainder (counter - 32) 42 != 0) and (remainder (counter - 38) 42
!= 0) [set timekeeper 2]
  if (remainder (counter - 3) 6 = 0) and (remainder (counter - 33) 42 != 0) and (remainder (counter - 39) 42
!= 0) [set timekeeper 3]
  if (remainder (counter - 4) 6 = 0) and (remainder (counter - 34) 42 != 0) and (remainder (counter - 40) 42
!= 0) [set timekeeper 4]
  if (remainder (counter - 5) 6 = 0) and (remainder (counter - 35) 42 != 0) and (remainder (counter - 41) 42
!= 0) [set timekeeper 5]
  if (remainder (counter - 6) 6 = 0) and (remainder (counter - 36) 42 != 0) and (remainder (counter - 42) 42
!= 0) [set timekeeper 6]
  if remainder (counter - 31) 42 = 0 [set timekeeper 7]
  if remainder (counter - 32) 42 = 0 [set timekeeper 8]
  if remainder (counter - 33) 42 = 0 [set timekeeper 9]
  if remainder (counter - 34) 42 = 0 [set timekeeper 10]
  if remainder (counter - 35) 42 = 0 [set timekeeper 11]
  if remainder (counter - 36) 42 = 0 [set timekeeper 12]
  if remainder (counter - 37) 42 = 0 [set timekeeper 13]
  if remainder (counter - 38) 42 = 0 [set timekeeper 14]
  if remainder (counter - 39) 42 = 0 [set timekeeper 15]
  if remainder (counter - 40) 42 = 0 [set timekeeper 16]
  if remainder (counter - 41) 42 = 0 [set timekeeper 17]
  if remainder (counter - 42) 42 = 0 [set timekeeper 18]
end

to find-days-activities
  ; Timekeeper values of 5, 6, 11, 12, 17 and 18 correspond to sleeping times when nothing happens, so
they are not included in the method at the present time. If activity of agents overnight is desired, the
appropriate times and corresponding methods must be added to the model.
  if timekeeper = 1  [do-MF610am-Acts]
  if timekeeper = 2  [do-MF10am2pm-Acts]
  if timekeeper = 3  [do-MF26pm-Acts]
  if timekeeper = 4  [do-MF610pm-Acts]
  if timekeeper = 7  [do-Sat610am-Acts]
  if timekeeper = 8  [do-Sat10am2pm-Acts]
  if timekeeper = 9  [do-Sat26pm-Acts]
  if timekeeper = 10 [do-Sat610pm-Acts]
  if timekeeper = 13 [do-Sun610am-Acts]
  if timekeeper = 14 [do-Sun10am2pm-Acts]
  if timekeeper = 15 [do-Sun26pm-Acts]
```

```
  if timekeeper = 16 [do-Sun610pm-Acts]
end

; It is assumed that stay-at-home dads only move within their dwellings every day except Sunday.
Although they can receive visitors, they do not go visiting and unlike mothers, they do not direct the
movement of their children. In the MF 10-2 and Sat 10-2 time steps, this means that 900 agents (children
< 5 years) do not move at all.

; See the Info tab for details on the timing of different activities and descriptions of each occ-type.
to do-MF610am-Acts
  if occ-type = 0 [move-home]

  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]]

  if occ-type = 2 [move-home]
  if occ-type = 3 [move-school]
  if occ-type = 4 [move-travel-clergy]
  if occ-type = 7 [move-home]
  if occ-type = 8 [move-school]
  if occ-type = 9 [move-home]
end

to do-MF10am2pm-Acts
  if occ-type = 0 [
    ; A mother with only school-aged children has a chance of going to the boat at this time step.
Ethnographic evidence suggests that women work at the docks fairly often, so the probability of
movement to boats is high. Otherwise, she can either visit someone or move within her home. The
visiting probability is low, under the assumption that if she does not move to the boat, there is likely some
reason for that. Her movement is completely independent of her household's for weekday visiting. On
Saturdays she will act the same as women with occ-type 7 in order to look after school-aged children.
    let prob0a random-float 1.0;
    ifelse prob0a <= .80
      [ifelse can-visit?
        [move-boat]
        [move-home]]
      [let prob0b random-float 1.0
       let fw-visit-group (turtle-set self) ; The fisherwoman's visit group consists only of herself
       let visit-building dwelling
       if (prob0b <= .20 and can-visit?)[
         set visit-building find-visit-dwelling (count fw-visit-group)
         ]
       move-group fw-visit-group visit-building
       ]; closes else
     ]; closes if occ-type 0]

  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]
     ]
```

```
  if occ-type = 2 [
    ; A fisherwoman has a chance of going to the boat at this time step. Ethnographic evidence suggests
that women work at the docks fairly often, so the probability of movement to boats is high. Otherwise,
she can either visit someone or move within her home. The visiting probability is low, under the
assumption that if she does not move to the boat, there is likely some reason for that. Her movement is
completely independent of the rest of her household.
    let prob2a random-float 1.0;
    ifelse prob2a <= .80
      [ifelse can-visit?
        [move-boat]
        [move-home]]
      [let prob2b random-float 1.0
       let fw-visit-group (turtle-set self) ; The fisherwoman's visit group consists only of herself
       let visit-building dwelling
       if (prob2b <= .20 and can-visit?)[set visit-building find-visit-dwelling (count fw-visit-group)]
       move-group fw-visit-group visit-building
       ]; closes else
     ]; closes if occ-type 2

  if occ-type = 3 [move-school]
  if occ-type = 4 [move-travel-clergy]

  if occ-type = 7 [
    ; Stay-at-home moms also control movement of agents in occ-type 9, i.e. women > 15 years old who
help with childcare and preschool-aged children. All agents present in the household are initially put on a
list, which is then pared down to include only the desired agents. The SAHM then decides whether to visit.
If so, she moves the entire group on the pared list to the chosen dwelling. If she chooses not to visit or
cannot find an available place to visit, she moves everyone to a new cell within her own residence. Within
the move-group method the can-visit? variable for everyone in the group as well as other agents present
in the visited dwelling is changed to false, which prohibits these individuals from moving again in the
same step.
    let prob7 random-float 1.0
    let household-set make-travel-group
    let travel-set []
    ask household-set [if occ-type = 7  or occ-type = 9 [set travel-set (turtle-set travel-set self)]]
    let visit-building dwelling
    if (prob7 <= .50 and can-visit?)[set visit-building find-visit-dwelling (count travel-set)]
    move-group travel-set visit-building
    ]

  if occ-type = 8 [move-school]
;  if occ-type = 9 [] ; Movement is controlled by case 700
end

to do-MF26pm-Acts
  if occ-type = 0 [
    ; If the agent went to the boat during the previous time step, she moves within the boat. Otherwise she
returns to or moves within her home (depending on if she went visiting the previous time step).
    ifelse present-location = boat-id
      [move-boat]
      [move-home]
    ]
```

```
  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]
    ]

  if occ-type = 2 [
    ; If the agent went to the boat during the previous time step, she moves within the boat. Otherwise she
returns to or moves within her home (depending on if she went visiting the previous time step).
    ifelse present-location = boat-id
      [move-boat]
      [move-home]
    ]

  if occ-type = 3 [move-school]
  if occ-type = 4 [move-travel-clergy]
  if occ-type = 7 [move-home]
  if occ-type = 8 [move-school]
  if occ-type = 9 [move-home]
end

to do-MF610pm-Acts
  set can-visit? true ; resets the can-visit? variable after all the agents are done with their weekday visiting
  ; Currently, all agents do the same activity in this time period. If different activities are desired, break out
by occ-type as in other time periods.
  move-home
end

to do-Sat610am-Acts
  if occ-type = 0 [move-home]

  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]
   ]

  if occ-type = 2 [move-home]
  if occ-type = 3 [move-home]
  if occ-type = 4 [move-travel-clergy]
  if occ-type = 7 [move-home]

  if occ-type = 8 [
    ; Ethnographic evidence suggests that any children 10 years or older who belong to a family with a
fisherman and/or boat have a high probability of going to work at their family's shore crew. In this
procedure, if they do not go to the boat/shore, they move within their house. Most likely, only older boys
would go during this time of day and help with fishing. Older girls would likely wait until later in the day.
At this time there is no differentiation between the sexes.
    let prob8 random-float 1.0
    ifelse (prob8 <= 0.8 and age >= 10)
      [move-boat]
      [move-home]
```

```
    ]

  if occ-type = 9 [move-home]
end

to do-Sat10am2pm-Acts
  if occ-type = 0 [
    ; On Saturdays, these mothers do not fish, and they also control movement of younger school-aged children (>5 and <10). All people present in the household are initially put on a list. That list is then pared down to include only the desired individuals. This pared list currently allows for inclusion of occ-type 9s (preschool children or mother's helpers). However, the way occ-types are assigned make it highly unlikely/impossible for 0s and 9s to be in the same household. The mother then decides whether to visit. If so, she moves the entire group on the pared list to the chosen dwelling. If she chooses not to visit or cannot find an available place to visit, she moves everyone to a new cell within her own residence. Within the move-group method the can-visit? variable for everyone in the group as well as other agents present in the visited dwelling is changed to false, which prohibits these individuals from moving again in the same step.
    let prob0 random-float 1.0
    let household-set make-travel-group
    let travel-set []
    ask household-set [if (occ-type = 0  or occ-type = 9 or (occ-type = 8 and age < 10)) [set travel-set (turtle-set travel-set self)]]
    let visit-building dwelling
    if (prob0 <= .50 and can-visit?)[set visit-building find-visit-dwelling (count travel-set)]
    move-group travel-set visit-building
    ]

  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]
    ]

  if occ-type = 2 [
    let prob2a random-float 1.0
    ifelse prob2a <= .80
      [ifelse can-visit?
        [move-boat]
        [move-home]]
      [let prob2b random-float 1.0
       let fw-visit-group (turtle-set self)
       let visit-building dwelling
       if (prob2b <= .20 and can-visit?)[set visit-building find-visit-dwelling (count fw-visit-group)]
       move-group fw-visit-group visit-building
       ]; closes else
     ]; closes if occ-type 2

  if occ-type = 3 [
    ; Teachers and clergymen, including teacher-caretakers, move independently from their families on Saturdays. They either visit other dwellings or they stay at home.
    let prob3 random-float 1.0
    let teach-visit-group (turtle-set self)
    let visit-building dwelling
```

```
    if (prob3 <= .50 and can-visit?)[set visit-building find-visit-dwelling (count teach-visit-group)]
    move-group teach-visit-group visit-building
    ]

  if occ-type = 4 [move-travel-clergy]

  if occ-type = 7 [
    ; Stay-at-home mothers behave essentially the same on Saturdays as they do during the week.
However, they also control movement of younger schoolchildren (>5 and < 10) in their household.
    let prob7 random-float 1.0
    let household-set make-travel-group
    let travel-set []
    ask household-set [if (occ-type = 7  or occ-type = 9 or (occ-type = 8 and age < 10))[set travel-set (turtle-
set travel-set self)]]
    let visit-building dwelling
    if (prob7 <= .50 and can-visit?)[set visit-building find-visit-dwelling (count travel-set)]
    move-group travel-set visit-building
    ]

  if occ-type = 8 [
    ; All fisher's children under 10 who have not gone somewhere with their mother (i.e. they are called in
the simulation before their mother) have a chance to go to school to "play" on Saturdays. If fishers' kids
age 10 and over went to the boat in the previous time step, they move within the boat, otherwise they
too have a chance to go to school. If these older children don't go to school or fish, they move within the
home (independently of the movement of others in the household)
    let prob8 random-float 1.0
    ifelse age < 10
      [if (can-visit? and prob8 <= 0.8) [
        move-school] ; closes if of can-visit/prob8
      ] ; closes if of age test. If the can-visit? is false or probability too high, young schoolchildren do nothing
- may be picked up by and move with mom/head of household
      [ifelse present-location = boat-id ; Determines activities of older schoolchildren
        [move-boat]
        [ifelse prob8 <= 0.8
          [ifelse can-visit?
            [move-school]
            [move-home]]
          [move-home]; closes else of prob8
        ]; closes else of present-location/boat
      ]; closes else of age test
    ] ;closes if occ-type 8

;  if occ-type = 9 [ ] ; Movement is controlled by case 700
end

to do-Sat26pm-Acts
  if occ-type = 0 [move-home]

  if occ-type = 1 [
    ifelse stay-at-home-dad?
      [move-home]
      [move-boat]
    ]
```

```
  if occ-type = 2 [
    ; If the agent went to the boat during the previous time step, she moves within the boat. Otherwise she returns to or moves within her home (depending on if she went visiting the previous time step).
    ifelse present-location = boat-id
      [move-boat]
      [move-home]
   ]

  if occ-type = 3 [move-home]
  if occ-type = 4 [move-travel-clergy]
  if occ-type = 7 [move-home]

  if occ-type = 8 [
    ; Any child who went to school or visiting in the previous time step goes home. Children who went to the boat move within the boat.
    ifelse (age < 10)
      [move-home]
      [ifelse present-location = boat-id
         [move-boat]
         [move-home]
       ];closes else age <10
    ] ; closes occ-type 8

  if occ-type = 9 [move-home]
end

to do-Sat610pm-Acts
  set can-visit? true ; resets the can-visit? variable after all the agents are done with their Saturday visiting
  ; Currently, all agents do the same activity in this time period. If different activities are desired, break out by occ-type as in other time periods.
  move-home
end

to do-Sun610am-Acts ; This model currently assumes that a) there is only one church service for each church and b) all agents attend church each week. Therefore, no alternative behaviors are allowed or necessary. Because of this, each agent moves independently to the church.
  move-church
end

to do-Sun10am2pm-Acts
  ; Currently, all agents do the same activity in this time period. If different activities are desired, break out by occ-type as in other time periods.
  move-home
end

to do-Sun26pm-Acts ; Agents will either visit (in family/household groups) or stay home (either alone or with visitors). The first adult agent in the household through the go method decides which activity will occur. As part of visit-Sunday, the family-can-move? variable is set to false to prevent further movement of the household members. The movement of all children is governed by adults.
  if family-can-move? [
    ifelse age > 15
      [visit-Sunday]
```

```
    [; children do nothing]
  ]
end

to do-Sun610pm-Acts
  set can-visit? true ; reset in preparation for visiting the next day.
  set family-can-move? true ; reset in preparation for next service
  ; Currently, all agents do the same activity in this time period. If different activities are desired, break out
by occ-type as in other time periods.
  move-home
end

;;Destination-Related Movement Methods

; The move-home method moves agents to or within their assigned dwellings at any time after model
initialization. If an agent attempts to move within a full house, it stays where it is. If an agent tries to enter
a filled home, it picks a different dwelling to go to temporarily, but it is not reassigned permanently.
to move-home
  set group-size 1 ; In the present model, only individuals call move-home, so group-size is set to one. If, in
future versions of the model, groups travel home together, group-size needs to be set to the size of the
travel group.
  let dest-patch -1 ; Initialized at an unrealistic value to prevent and/or identify unintended errors.
  let home-patches (patch-set patches with [building-id = [dwelling] of myself and not occupied?])
  ifelse any? home-patches
    [set dest-patch one-of home-patches] ; closes if of any? home-patches
    [ifelse present-location != dwelling
      [let dest-dwelling find-visit-dwelling (group-size)
       let visit-dest-patches (patch-set patches with [building-id = dest-dwelling and not occupied?])
       set dest-patch one-of visit-dest-patches] ; If not at home, find a dwelling to visit.
      [set dest-patch patch-here] ; If already at home, but there are no other free cells, do nothing/stay
where you are.
     ] ; closes else of any? home-patches

  assign-location (dest-patch)
end

; The move-school method sends agents to school when it is called (by school-aged children, teachers and
clergy who also serve as teachers). If no space is available, the agent stays where it is. This model assumes
the community has only one school which is reasonable for early 20th century Newfoundland.
to move-school
  let dest-patch -1
  let school-patches (patch-set patches with [building-type = 2 and not occupied?])
  ifelse any? school-patches
   [set dest-patch one-of school-patches] ; closes if of any? home-patches
    [set dest-patch patch-here]  ; If no space at school, stay where you are. Closes else of ifelse

  assign-location (dest-patch)
end

; The move-boat method sends agents to their assigned boat. An agent's boat-id determines the specific
boat assignment. Fishermen call this method during the day every Monday to Saturday. Fisherwomen call
the method with a specified probability on those days, depending on their occ-type (related to childcare
```

responsibilities). Fishers' children >= 10 years old call this method on Saturdays with a specified probability. If no space is available, the agent stays where it is.

```
to move-boat
  let dest-patch -1
  let boat-patches (patch-set patches with [building-id = [boat-id] of myself and not occupied?])
  ifelse any? boat-patches
   [set dest-patch one-of boat-patches] ; closes if of any? home-patches
   [set dest-patch patch-here]  ; If no space at boat, stay where you are. Closes else of ifelse

  assign-location (dest-patch)
end
```

; Travelling clergy (occ-type 4) move to the lower right corner to indicate when they are "out" of the NI community. Future extensions of the model might include allowing these agents to visit different dwellings or "work" at the church during the week.

```
to move-travel-clergy
  let dest-patch patch 99 0
  assign-location (dest-patch)
end
```

; The move-church method is called by all agents individually on Sunday mornings. Each agent is assigned to a specific church, and church sizes should be set so all agents assigned to a church can find a space. This space criterion may fail, however, especially if children are adopted into households assigned to another church. If space cannot be found, the agent stays at its current location. Note there is currently no code to ensure a place is reserved for the pastor.

```
to move-church
  let dest-patch -1
  let church-patches (patch-set patches with [building-id = [church] of myself and not occupied?])
  ifelse any? church-patches
    [set dest-patch one-of church-patches] ; closes if of any? church-patches
    [set dest-patch patch-here
     type agt-id type " at tick: " type ticks + 1 type " cannot find an open patch at church: " print church
     ]

  assign-location (dest-patch)
end
```

; The visit-Sunday method governs movement of family groups, who may visit other dwellings on Sunday afternoons after church. This method is only called by the FIRST adult agent in a household who calls the go method. Any other adults and all children in a household do not call the method; their movement is based on the decisions made by the agent who calls this method. The probability of visiting is set higher than during the week, because Sunday is a day for socializing.

```
to visit-Sunday
  let Sunday-travel-group make-travel-group
  let prob random-float 1.0
  let visit-dwelling dwelling
  if (prob <= 0.5 and can-visit?)[set visit-dwelling find-visit-dwelling (count Sunday-travel-group)]

  move-group Sunday-travel-group visit-dwelling

  ask Sunday-travel-group [set family-can-move? false]
end
```

```
;;Movement Submethods

;; Procedure for finding a dwelling to visit
to-report find-visit-dwelling [group-num]
  let counter 0
  let visit-dwelling-id one-of house-list
  let available-cells 0
  set available-cells count patches with [building-id = visit-dwelling-id and not occupied?]
  while [(counter <= (num-houses * 10)) and ((group-num > available-cells) or (available-cells = count patches with [building-id = visit-dwelling-id]) or (visit-dwelling-id = dwelling))][
    set visit-dwelling-id one-of house-list
    set available-cells count patches with [building-id = visit-dwelling-id and not occupied?]
    set counter counter + 1
    ]
  ; If unable to find a dwelling to visit within the maximum allowed attempts, set the visit-dwelling to be the calling agent's dwelling.
  if counter > (num-houses * 10) [set visit-dwelling-id dwelling]

  report visit-dwelling-id
end

; This method should only be called when "destination" (a specific patch) is known to be available at the desired building. The initial error statement is a "double-check" but should never be needed.
to assign-location [destination]
  ask patch-here [set occupied? false]
  ifelse destination = nobody
    [print "ERROR IN ASSIGN-LOCATION. DESTINATION = NOBODY"]
    [setxy [pxcor] of destination [pycor] of destination]
  set present-location [building-id] of patch-here
  ask patch-here [set occupied? true]
end

; This method makes a set of members of the same household currently in the same building as the calling agent to be used for group movement. If more general traveling groups are desired, the criteria for membership should be adjusted or an analogous new method is needed. The turtle-set is limited to SA-agents to prevent inclusion of turtles assigned to the ghost breed.
to-report make-travel-group
  let residents-set []
  let occupants (turtle-set NI-agents-on patches with [building-id = [present-location] of myself])
  ask occupants [if household = [household] of myself [set residents-set (turtle-set residents-set self)]]
  report residents-set
end

; The move-group method allows a group to visit another place. It is called by any agent directing the movement of a group, or in certain cases in directing their own movement. It requires the ID of the building to be visited and all the agents in the traveling group, both of which are determined prior to the method call. The calling agent should ensure that the desired destination contains enough space for the entire group. The group then moves to that building.
to move-group [group-set visit-bldg]
  ask group-set [
  let visit-patches (patch-set patches with [building-id = visit-bldg and not occupied?])
  let dest-patch nobody
  ifelse count visit-patches = 0
```

```
  ; In certain situations, a group may need to remain in a completely full building, for example when being
visited by a sufficiently large group. In such cases, there would be no unoccupied cells so each agent must
stay at their current patch.
    [set dest-patch patch-here]
    [set dest-patch one-of visit-patches]
  assign-location (dest-patch)
  ]

  ; The following code governs the change of the appropriate boolean variables for the building type being
visited (canVisit for now; others may be added later). The values are changed to ensure that agent
movement follows appropriate constraints (e.g. canVisit = false when a group visits someone else or is
being visited).
  let occupant-set (turtle-set NI-agents-on patches with [building-id = visit-bldg])
  ask occupant-set [if [building-type] of patch-here = 1 [set can-visit? false]]
end

;;Disease Methods

; A NI-agent method called near the beginning of the go method. Depending on their current disease
status and the value of relevant timing variables, NI-agents will transition to the next disease status or
reduce the time remaining for the current status (or die, with some probability, if they are infectious). The
durations of disease stages are equal for all agents.
to update-disease-status

  ; Susceptible NI-agents do nothing

  ; Exposed agents must check the value of time-to-infectious to see if they should become infectious this
time period:
  if disease-status = 1 [
    ifelse time-to-infectious = 0
       [set disease-status 2
        set newly-infectious? true
        set time-to-recovery infectious-period
        set color red]
       [set time-to-infectious time-to-infectious - 1]
     ] ; closes if =1

  ; Infectious agents first check whether they will die this time period. If they survive, they must check the
value of time-to-recovery to see if they should recover this time period.
  if disease-status = 2 [
    if not newly-infectious? [
      let death-threshold random-float 1.0
      if death-threshold <= death-prob [create-ghost]
      ]

    ifelse time-to-recovery = 0 and disease-status = 2 ; The ifelse statement includes the disease-status
component so agents who die this tick don't override changes made in kill-node
      [set disease-status 3
       set color violet]
      [set time-to-recovery time-to-recovery - 1]
      ]

  ; Recovered NI-agents do nothing.
```

```
end

; The following two methods assign a random probability of transmission to a contact between an
infectious and a susceptible agent. When such a contact occurs, the method compares the parameter
value of the transmission probability to the random probability. If the transmission probability is greater
than or equal to the random probability, then disease transmission occurs and the susceptible agent
moves into the exposed state. The length of time in the exposed class is determined by the parameter
latent-period, which is assumed to be constant for all agents. The code can be modified to allow for a
variable latent period. If the transmission probability parameter is less than the random probability, the
susceptible agent does not change disease status.
to transmit-from [infectors-set] ; called by a susceptible agent
  let susc-agent self
  let prob random-float 1.0
  ask infectors-set [
    if (disease-status = 2 and prob <= transmission-prob and not [newly-infected?] of susc-agent) [ ; The
condition for disease-status is not strictly necessary; the infectors-set should only include neighboring
agents who are infectious.
      ; The following if statement ensures that transmission can only occur between agents in the same
building or along the border of adjacent boats.
      if ((building-id = [building-id] of susc-agent) or (building-type = 4 and [building-type] of susc-agent = 5)
or (building-type = 5 and [building-type] of susc-agent = 4))[
      ask susc-agent [
        set disease-status 1
        set color yellow
        set time-to-infectious latent-period - 1 ; The subtract one takes the present time tick into account.
NOTE: If no latent period is desired, i.e. the infected agent becomes infectious immediately,
corresponding code will need to be changed. For example, update-disease-status will not work correctly
with this - 1 adjustment.
        set time-infected ticks + 1  ; The plus one is to correct the timing since ticks increment at the end of
the go method and thus it is recording the previous value of ticks during the current go.
        set place-infected [building-id] of patch-here
        set infector-id [agt-id] of myself ; myself refers to the member of infectors-set who called the above
"ask susc-agent".
        set infector-occ [occupation] of myself
        set infector-dwelling [dwelling] of myself
        set newly-infected? true
        ] ] ] ]
end

to transmit-to [new-cases-set] ; called by an infectious agent
  let infector-agent self
  let prob random-float 1.0
  ask new-cases-set [
    if (disease-status = 0 and prob <= transmission-prob) [ ; The condition for disease-status is not strictly
necessary; the new-cases-set should only include neighboring agents who are susceptible.
      ; The following if statement ensures that transmission can only occur between agents in the same
building or along the border of adjacent boats.
      if ((building-id = [building-id] of infector-agent) or (building-type = 4 and [building-type] of infector-
agent = 5) or (building-type = 5 and [building-type] of infector-agent = 4))[
      set disease-status 1
      set color yellow
      set time-to-infectious latent-period
```

```
     set time-infected ticks + 1  ; The plus one is to correct the timing since ticks increment at the end of
the go method and thus it is recording the previous value of ticks during the current go.
     set place-infected [building-id] of patch-here
     set infector-id [agt-id] of infector-agent
     set infector-occ [occupation] of infector-agent
     set infector-dwelling [dwelling] of infector-agent
     set newly-infected? true
     if step-completed? [; If the new case has already completed its behavior for the current time step, this
adjustment accounts for this tick. Otherwise, the timing variables are decremented appropriately in
update-disease-status when the agent completes its step.
       set time-to-infectious time-to-infectious - 1 ; NOTE: If no latent period is desired, i.e. the infected
agent becomes infectious immediately, corresponding code will need to be changed. For example,
update-disease-status will not work correctly with this - 1 adjustment.
       ] ] ] ]
end

;;Death-Related Methods

;This method is called by an NI-agent who has died. It records death-related variables and creates a new
turtle in the breed "ghosts" with the same attributes as the calling agent. The calling agent is then moved
to the cemetery (coordinates of 1, 1). The ghost remains at the location where the agent died.
to create-ghost
  set shape "ghost"
  set color gray + 1
  set disease-status 4
  set newly-dead? true
  set time-died ticks + 1 ; as in the transmission methods above, the + 1 needs to correct for how the go
method keeps track of time
  set place-died [building-id] of patch-here

  hatch-ghosts 1[
    set size 2
    set shape "ghost"
    ask patch-here [set occupied? false]
    hide-turtle ; users can control whether the ghost is hidden with this statement.
  ]

  setxy 1 1

  ; The following statements set the size of ghosts in the cemetery to be proportional to the number of
ghosts, in order to provide a visualization of the number of deaths during the simulated epidemic. At
present, this code results in multiple visible ghosts superimposed on one another. The ghosts are also
centered on patch (1,1) so when the ghost is large enough, only part of it can be seen.
;  let prop-ghosts (count ghosts / pop-size)
;  if prop-ghosts > 0.01 [set size floor (prop-ghosts * 50)]
end

;The reassign-occupation method is called by each agent upon its death.
to reassign-occupation
  set children-under-five? false

  let dying-agent self
```

```
  let live-children (turtle-set NI-agents with [age <= 15 and disease-status != 4 and household =
[household] of dying-agent]); This set is used during procedures identifying new caretakers for children of
a dying agent who is a primary caretaker. Therefore, the set only needs to contain children assigned to
the same household as the dying agent.
  let live-adults (turtle-set NI-agents with [disease-status != 4 and age > 15])

;  type "Agent: " type agt-id type " with occ-type " type occ-type print " is dying/calling reassign-occ."

  if age > 15 [if any? live-children with [age < 5][set children-under-five? true]]

  if any? live-adults [ ; There must be at least one live adult in the community if any replacements are to
occur.
  if occ-type = 0 [
    ; Occ-type 0s with children at home call find-caretaker to search for a new caretaker from available
adults. If a new caretaker is identified, it needs to change occupation-related variables to reflect
caretaking duties. If the caretaker is in a different household, the adopted children need to change
residence-related variables. If no suitable caretaker is available, the children are adopted "out" of the
community as part of the find-caretaker method.
    if any? live-children [
      let new-ct0 find-caretaker live-adults live-children
      if new-ct0 != nobody [
        reassign-ct-occ new-ct0
        if household != [household] of new-ct0 [reassign-adopted-kids live-children new-ct0]
        ] ] ]

  if occ-type = 1 [
    ; Occ-type 1s with childcare duties need to find caretakers for any surviving children, following the same
procedures as occ-type 0s.
    if ((stay-at-home-dad? or fisherman-caretaker?) and any? live-children) [
      let new-ct1 find-caretaker live-adults live-children
      if new-ct1 != nobody [
        reassign-ct-occ new-ct1
        if household != [household] of new-ct1 [reassign-adopted-kids live-children new-ct1]
        ] ] ]

  if occ-type = 2 [
    ; Occ-type 2s with childcare duties need to find caretakers for any surviving children, following the same
procedures as occ-type 0s.
    if any? live-children [
      let new-ct2 find-caretaker live-adults live-children
      if new-ct2 != nobody [
        reassign-ct-occ new-ct2
        if household != [household] of new-ct2 [reassign-adopted-kids live-children new-ct2]
        ] ] ]

  if occ-type = 3 [
    ; If a pastor or teacher dies, a replacement is always chosen, unless no suitable agent is available. Pastor
replacements are drawn from adult males while teachers (female) are drawn from fisherwomen. If
pastor/teachers (males) are also teacher-caretakers, they need to find caretakers for any children under
their care. Female teachers are not allowed to adopt and thus are never caretakers.
    let pastor-found? false
    let teacher-found? false
```

```
  ifelse sex = 0 ; male (pastor/teachers)
    [if (teacher-caretaker? and any? live-children) [
     let new-ct3 find-caretaker live-adults live-children
     if new-ct3 != nobody [
      reassign-ct-occ new-ct3
      if household != [household] of new-ct3 [reassign-adopted-kids live-children new-ct3]
     ] ]
    ; Because of how potential replacements are prioritized, this agent will likely not be and does not
need to be the same agent selected above as the new caretaker.
    set pastor-found? choose-pastor pastor-found? live-adults
    if not pastor-found? [print "New 300 pastor could not be found."]
    ] ; closes if of sex test

  ; else (female teachers)
    [set teacher-found? choose-teacher teacher-found? live-adults
    if not teacher-found? [print "New female teacher could not be found."]
    ] ; closes else of sex test
  ]

 if occ-type = 4 [
  ; This clergyman always chooses a replacement, unless no suitable agent is available.
  let travel-clergy-found? false
  set travel-clergy-found? choose-travel-clergy travel-clergy-found? live-adults
  if not travel-clergy-found? [print "No replacement travel clergy could be found"]
  ]

 if occ-type = 7 [
  ; Occ-type 7s with children at home need to find caretakers for any surviving children, following the
same procedures as occ-type 0s.
  if any? live-children [
   let new-ct7 find-caretaker live-adults live-children
   if new-ct7 != nobody [
    reassign-ct-occ new-ct7
    if household != [household] of new-ct7 [reassign-adopted-kids live-children new-ct7]
    ] ] ]

 if occ-type = 8 [ ; Dying children need to see if they are the last child who needs to be cared for by a male
caretaker. If not, the male caretaker may return to his previous activities
  restore-dad live-children live-adults
  ]

 if occ-type = 9 [ ; Dying children need to see if they are the last child who needs to be cared for by a male
caretaker. If not, the male caretaker may return to his previous activities.
  ; If any individuals in this occ-type are > 15 years old, they do not replace themselves
  restore-dad live-children live-adults
  ] ]
end

; The find-caretaker method looks for potential replacement caretakers among adults, prioritized by
residence and/or relationship to the dying agent. It first looks among members of the same household,
then members of the same dwelling (different household), then members of the same extended family
(indicated by common surname), then among any suitable adults in the community. If no caretaker is
```

available, any live children are adopted "out" of the community. This method ultimately returns the agent/object that is selected as the new caretaker to the agent calling the method.

```
to-report find-caretaker [living-adults living-kids]
  ; Note that the associated boolean variables for these methods do not need to be (re)set as false. They are initialized as such and are changed here for the dying-agent who, of course, can only die once.
  if any? living-kids [
    find-sameHH-carer (living-adults)
    if not sameHH-caretaker-found? [
      find-sameDW-carer (living-adults)
      if not sameDW-caretaker-found? [
        find-extfam-carer (living-adults)
        if not extfam-caretaker-found? [
          find-any-carer (living-adults)
          if not any-caretaker-found? [
            leave-village (living-kids)
          ] ] ] ] ]

  report new-caretaker
end

; The find-sameHH-carer method creates agent-set(s) of NI-agents with matching household to be potential caretakers. Multiple sets are used to prioritize, i.e. first 0/7, then 2/9 >15, then fishermen, then teachers/clergy. The last group will only become caretakers for school-aged children.
to find-sameHH-carer [poss-carers]
  let dying-agent self

  let poss-07female-caretakers (turtle-set poss-carers with [(occ-type = 0 or occ-type = 7) and household = [household] of dying-agent])
  ; Note that there is only one agent assigned to occ-type 0 or 7 per household. Therefore, if one of these agents dies, there will be none left in the household. If this method is called by a male caretaker, that individual only became the caretaker because all the females had been exhausted. The ONLY time a dying agent could produce any agents in the 0/7 category is when a female of occ-type 2, for example an older daughter of a mother with occ-type 0, calls this method. In this scenario, the 0/7 test is used to identify if there is already a caretaker in the household rather than to find a new/replacement caretaker.

  let poss-29female-caretakers (turtle-set poss-carers with [(occ-type = 2 or occ-type = 9) and household = [household] of dying-agent])

  let poss-male-caretakers (turtle-set poss-carers with [occ-type = 1 and household = [household] of dying-agent])

  let poss-teacher-caretakers no-turtles
  if not [children-under-five?] of dying-agent [set poss-teacher-caretakers (turtle-set poss-carers with [occ-type = 3 and sex = 0 and household = [household] of dying-agent])]
  ; Poss-teacher-caretakers includes any resident male pastors who are also teachers (but does not include traveling pastors, who are occ-type 4)

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set new-caretaker to be the identified caretaker
  ifelse any? poss-07female-caretakers
    [ask one-of poss-07female-caretakers [
        ask dying-agent [
          set new-caretaker myself
```

```
          set sameHH-caretaker-found? true]]]; closes if 07
    [ifelse any? poss-29female-caretakers
       [ask one-of poss-29female-caretakers [
          ask dying-agent [
            set new-caretaker myself
            set sameHH-caretaker-found? true]]] ; closes if poss29
       [ifelse any? poss-male-caretakers
          [ask one-of poss-male-caretakers [
             ask dying-agent [
               set new-caretaker myself
               set sameHH-caretaker-found? true]]] ; closes if male
          [if any? poss-teacher-caretakers [
             ask one-of poss-teacher-caretakers [
               ask dying-agent [
                 set new-caretaker myself
                 set sameHH-caretaker-found? true]]]]] ; closes else male
       ] ; closes else poss29
   ] ; closes else poss07
end

; The find-sameDW-carer method creates agent-set(s) of NI-agents who live in the same dwelling as the dying agent, but are assigned to a different household (SDDH). Multiple sets are used to prioritize, i.e. first 0/7, then 2, then fishermen, then teachers/clergy. 9s over age 15 would never become caretakers, because they only live in households with 7s who would be chosen first (and if the 7 dies, a 9 would become a 7). Male teachers/clergy can only adopt school-aged kids.

; In the study community, all dwellings with multiple households consist of individuals who are (apparently) closely related, so it is reasonable to assume that these SDDH individuals would be the first choice caretakers after all SDSH adults have died. In communities where different households might represent boarders or servants, this assumption becomes unrealistic. The code below may need to be modified to exclude such individuals from possible caretaker turtle-sets.
to find-sameDW-carer [poss-carers]
  let dying-agent self

  let poss-07female-caretakers (turtle-set poss-carers with [(occ-type = 0 or occ-type = 7) and dwelling = [dwelling] of dying-agent and household != [household] of dying-agent])
  ; The "household != [household]" technically unnecessary since they failed the find-same-household method.

  let poss-2female-caretakers (turtle-set poss-carers with [occ-type = 2 and dwelling = [dwelling] of dying-agent and household != [household] of dying-agent])

  let poss-male-caretakers (turtle-set poss-carers with [occ-type = 1 and dwelling = [dwelling] of dying-agent and household != [household] of dying-agent])

  let poss-teacher-caretakers no-turtles
  if not [children-under-five?] of dying-agent [set poss-teacher-caretakers (turtle-set NI-agents with [occ-type = 3 and sex = 0 and dwelling = [dwelling] of dying-agent and household != [household] of dying-agent])]

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set new-caretaker to be the identified caretaker
  ifelse any? poss-07female-caretakers
```

```
  [ask one-of poss-07female-caretakers [
   ask dying-agent [
    set new-caretaker myself
    set sameDW-caretaker-found? true]]] ; closes if of poss07
  [ifelse any? poss-2female-caretakers
   [ask one-of poss-2female-caretakers [
    ask dying-agent [
     set new-caretaker myself
     set sameDW-caretaker-found? true]]] ; closes if of poss2
   [ifelse any? poss-male-caretakers
    [ask one-of poss-male-caretakers [
     if any? other NI-agents with [household = [household] of myself and occ-type = 1][ ; This segment of
code ensures there is only one male caretaker in a household.
      ask other NI-agents with [household = [household] of myself and occ-type = 1][
       if fisherman-caretaker? or stay-at-home-dad? [
        ask dying-agent [
         set new-caretaker myself
         set sameDW-caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-
existing fisherman caretaker in the selected household
     if not [sameDW-caretaker-found?] of dying-agent [
      ask dying-agent [
       set new-caretaker myself
       set sameDW-caretaker-found? true]]]] ; closes if of poss fishermen
    [if any? poss-teacher-caretakers [
     ask one-of poss-teacher-caretakers [
     if any? other NI-agents with [household = [household] of myself and occ-type = 3][ ; This segment of
code ensures there is only one teacher caretaker in a household.
      ask other NI-agents with [household = [household] of myself and occ-type = 3][
       if teacher-caretaker? [
        ask dying-agent [
         set new-caretaker myself
         set sameDW-caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-
existing teacher-caretaker in the selected household
     if not [sameDW-caretaker-found?] of dying-agent [
      ask dying-agent [
       set new-caretaker myself
       set sameDW-caretaker-found? true]]]] ; closes if any? poss teacher
    ]; closes else of possfishermen
   ]; closes else of poss29
  ]; closes else of poss07
end

; The find-extfam-carer method creates agent-set(s) of NI-agents who have some relationship (i.e. are
members of the same extended family) to the newly-dead agent but aren't in the same dwelling. Multiple
sets are used to prioritize, i.e. first 0/7, then 2, then fishermen. As above, 9s over age 15 would have
switched to occ-type 7 earlier if needed to be caretakers and would never become caretakers while
assigned to occ-type 9. Unlike the previous methods, teachers/clergy are not considered potential
caretakers; it is assumed that these agents will only step in to adopt children from their own dwelling.
to find-extfam-carer [poss-carers]
 let dying-agent self

 let poss-07female-caretakers (turtle-set poss-carers with [(occ-type = 0 or occ-type = 7) and dwelling !=
[dwelling] of dying-agent and ext-family = [ext-family] of dying-agent])
```

```
  ; The dwelling test is technically unnecessary because the agent will have failed the same or other household (same dwelling) tests above.

  let poss-2female-caretakers (turtle-set poss-carers with [occ-type = 2 and dwelling != [dwelling] of dying-agent and ext-family = [ext-family] of dying-agent])

  let poss-male-caretakers (turtle-set poss-carers with [occ-type = 1 and dwelling != [dwelling] of dying-agent and ext-family = [ext-family] of dying-agent])

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set new-caretaker to be the identified caretaker
  ifelse any? poss-07female-caretakers
   [ask one-of poss-07female-caretakers [
      ask dying-agent [
        set new-caretaker myself
        set extfam-caretaker-found? true]]] ; closes if of poss07
   [ifelse any? poss-2female-caretakers
     [ask one-of poss-2female-caretakers [
        ask dying-agent [
          set new-caretaker myself
          set extfam-caretaker-found? true]]] ; closes if of poss2
     [if any? poss-male-caretakers [
       ask one-of poss-male-caretakers [
         if any? other NI-agents with [household = [household] of myself and occ-type = 1][ ; This segment of code ensures there is only one male caretaker in a household.
           ask other NI-agents with [household = [household] of myself and occ-type = 1][
             if fisherman-caretaker? or stay-at-home-dad? [
               ask dying-agent [
                 set new-caretaker myself
                 set extfam-caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-existing fisherman caretaker in the selected household
         if not [extfam-caretaker-found?] of dying-agent[
           ask dying-agent [
             set new-caretaker myself
             set extfam-caretaker-found? true]]]] ; closes if any poss male
       ]; closes else of poss2
     ]; closes else of poss07
end

; The find-any-carer method creates agent-set(s) of NI-agents who did not meet the criteria in previous methods, i.e. they live in a different dwelling and are not part of the dying caretaker's extended family. Multiple sets are used to prioritize, i.e. first 0/7, then 2, then males. 9s over age 15 would never become caretakers, because they only live in households with 7s who would be chosen first (and if the 7 dies, a 9 would become a 7). As with the extfamily method, teachers/clergy are not allowed to adopt in this scenario.
to find-any-carer [poss-carers]
  let dying-agent self

  let poss-07female-caretakers (turtle-set poss-carers with [(occ-type = 0 or occ-type = 7) and dwelling != [dwelling] of dying-agent and ext-family != [ext-family] of dying-agent])

  let poss-2female-caretakers (turtle-set poss-carers with [occ-type = 2 and dwelling != [dwelling] of dying-agent and ext-family != [ext-family] of dying-agent])
```

```
  let poss-male-caretakers (turtle-set poss-carers with [occ-type = 1 and dwelling != [dwelling] of dying-agent and ext-family != [ext-family] of dying-agent])

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set new-caretaker to be the identified caretaker
  ifelse any? poss-07female-caretakers
   [ask one-of poss-07female-caretakers [
      ask dying-agent [
        set new-caretaker myself
        set any-caretaker-found? true]]] ; closes if of poss-07
   [ifelse any? poss-2female-caretakers
     [ask one-of poss-2female-caretakers [
        ask dying-agent [
          set new-caretaker myself
          set any-caretaker-found? true]]]
     [if any? poss-male-caretakers [
       ask one-of poss-male-caretakers [
         if any? other NI-agents with [household = [household] of myself and occ-type = 1][ ; This segment of code ensures there is only one male caretaker in a household.
           ask other NI-agents with [household = [household] of myself and occ-type = 1][
             if fisherman-caretaker? or stay-at-home-dad? [
               ask dying-agent [
                 set new-caretaker myself
                 set any-caretaker-found? true]]]]] ; closes if any? test that checks whether there's a pre-existing fisherman caretaker in the selected household
         if not [any-caretaker-found?] of dying-agent [
           ask dying-agent [
             set new-caretaker myself
             set any-caretaker-found? true]]]] ;closes if any? fishermen
       ] ; closes else of poss-29
     ] ; closes else of poss-07
end

; This method is called if no caretaker is available. The children of the dying agent are adopted "out" of the community.
to leave-village [new-orphans]
  ask new-orphans [
    set num-orphans-gone num-orphans-gone + 1
    if disease-status != 0 [
      set num-infected-orphans-gone num-infected-orphans-gone + 1]
    set time-leaves-village ticks + 1
    setxy 99 99
    set breed orphans
    set shape "circle"
  ]
  set new-caretaker nobody
end

; When a new caretaker adopts children, it (may) need to change its occupation roles to reflect its new responsibilities.
to reassign-ct-occ [new-carer]
  let dead-agent self
```

```
  ask new-carer [
    if occ-type != 3 and occ-type != 7 and not stay-at-home-dad? [ ; these agents do not change their occupation variables when they adopt new or additional children
      ifelse sex = 1  ; new caretaker is female
        [ifelse [sex] of dead-agent = 0 ; previous caretaker is male
        ; If a 0, 2 or 9 female is taking over caretaking duties for a dad with children under five, she needs to become occ-type 7. Otherwise, if the children are all school-aged, she stays or becomes occ-type 0.
          [ifelse [stay-at-home-dad?] of dead-agent
            [set occ-type 7
             let occ-part remainder occupation 100
             set occupation occ-part + 700] ; closes if stayathomedad?
            [set occ-type 0
             let occ-part remainder occupation 100
             set occupation occ-part]]; closes else stayathomedad and if sex of dying node
          [;if a 0, 2 or 9 female is taking over caretaking duties from another female, she needs to be set to the same occupation as the original caretaking female but with her own fishing boat assignment. The only time this would not be the case is if a 0 is taking over for a 2; this woman would need to remain a 0 because she may still have younger (5-9 year old) children in her care.
           ifelse (occ-type = 0 and [occ-type] of dead-agent = 2)
             [ ; do nothing.]
             [set occ-type [occ-type] of dead-agent
              let occ-part remainder occupation 100
              set occupation occ-type * 100 + occ-part] ; closes else of occ-type 0/2
           ] ; closes else sex of dying node
         ] ; closes if (new caretaker is female)
        ;If the new caretaker is a fisherman (the only male occ-type that would be considered here), he must become a stay-at-home dad if there are kids < 5. These males will set a boolean variable true reflecting their appropriate changes but otherwise retain their occupation codes of 1XX.
        [ifelse [children-under-five?] of dead-agent
          [set stay-at-home-dad? true
           set fisherman-caretaker? false]
          [set fisherman-caretaker? true]
         ] ; closes else (new caretaker is male)
       ] ; closes if occ-type

    if occ-type = 3 and not [children-under-five?] of dead-agent [ ; Teachers who become caretakers (to school-aged children only) don't change their occupation variables but do need to change a boolean reflecting their new status. The test for chidlren's ages here is for added caution. The occ-type 3 agent should not have been selected as the caretaker if there were preschool-aged children being adopted
      set teacher-caretaker? true]
  ]
end

; If children are adopted into a different household, they need to change residence-related variables to values matching their new household's. If they are adopted by an adult in the same household, no such changes are necessary.
to reassign-adopted-kids [alive-kids new-carer]
  ask alive-kids [
    set dwelling [dwelling] of new-carer
    set household [household] of new-carer
    set boat-id [boat-id] of new-carer
    set church [church] of new-carer
```

```
  ; extfam will not be changed. This information can be used to test hypotheses related to family, etc. No
other variables need to be changed, as they are not dependent on where the child lives or who cares for
them. This includes occupation as most method calls rely on occ-type (occupation is recorded during
transmission, however, so this should be taken into account in any analyses of case data files).
 ]
end

; The restore-dad method is called by newly-dead ghosts who are kids <=15. These agents check whether
there are any surviving siblings and the ages of those children. If there are no siblings at all, the first block
of code allows fisherman- and teacher-caretakers to return to their previous status, but the change in
status of stay-at-home-dads is delayed until the next block of code. If there are no surviving siblings under
5 years of age (the second block of code), stay-at-home-dads either become fisherman-caretakers (i.e.
there are surviving school-aged siblings) or return to non-caretaker fisherman status (i.e. there are no
surviving siblings at all). Female caretakers do not return to previous occupations even if there are no
surviving siblings.
to restore-dad [alive-kids alive-agents]
 let dying-kid self
 let preschool-siblings (turtle-set alive-kids with [age < 5])

 if not any? alive-kids [
  let poss-dads (turtle-set alive-agents with [household = [household] of dying-kid and sex = 0 and age >
15])
  if any? poss-dads [
   ask poss-dads [
    if teacher-caretaker? [set teacher-caretaker? false]
    if fisherman-caretaker? [set fisherman-caretaker? false]
   ] ] ]

 if not any? preschool-siblings [
  let poss-sahds (turtle-set alive-agents with [household = [household] of dying-kid and sex = 0 and age >
15])
  if any? poss-sahds [
   ask poss-sahds [
    if stay-at-home-dad? [set stay-at-home-dad? false]
    if any? alive-kids and occ-type = 1 [set fisherman-caretaker? true] ; Teacher-caretakers should not set
this variable true
   ] ] ]
end

; The choose-pastor method picks an adult male fisherman over age 30 from the same church as the
deceased pastor. The chosen fisherman's boat must have at least 3 fishermen assigned to it prior to
reassigning the replacement (i.e. boat is left with 2 men).
to-report choose-pastor [agent-found? alive-agents]
 let dying-agent self
 let poss-pastors (turtle-set alive-agents with [occ-type = 1 and age > 30 and church = [church] of dying-
agent and not stay-at-home-dad?])

 if any? poss-pastors[
  ask poss-pastors [
   if not agent-found? [
   let num-fishermen count alive-agents with [boat-id = [boat-id] of myself and occ-type = 1]
   if num-fishermen > 2 [
    set occ-type 3
```

```
    let occ-part remainder occupation 100
    set occupation occ-part + 300
    set agent-found? true]
   ] ] ]

 report agent-found?
end

; The choose-teacher method picks a fisherwoman from any boat with at least 2 fisherwomen currently
assigned to it (i.e. the boat is left with 1 fisherwoman). The chosen fisherwoman's occupation is set to
that of the calling agent.
to-report choose-teacher [agent-found? alive-agents]
 let dying-agent self
 let poss-teachers (turtle-set alive-agents with [occ-type = 2])

 if any? poss-teachers[
  ask poss-teachers [
   if not agent-found?[
   let num-fisherwomen count alive-agents with [boat-id = [boat-id] of myself and (occ-type = 0 or occ-
type = 2)]
   if num-fisherwomen > 1 [
    set occ-type 3
    let occ-part remainder occupation 100
    set occupation occ-part + 300
    set agent-found? true]
   ] ] ]

 report agent-found?
end

; The choose-travel-clergy method picks an adult male fisherman over age 25 from the same church as the
deceased pastor. The chosen fisherman's boat must have at least 3 fishermen assigned to it prior to
reassigning the replacement (i.e. boat is left with 2 men). Although "choose-pastor" restricts replacement
pastors/teachers to individuals over age 30, this occupation allows slightly younger replacements. The
initial agent assigned to this category is 27 y o. It is assumed that a person in this general role may be a
missionary or early in his career. Further, replacements are restricted to agents who do not have childcare
duties for similar reasons that prevent occ-type 4 from adopting.
to-report choose-travel-clergy [agent-found? alive-agents]
 let dying-agent self
 let poss-travelers (turtle-set alive-agents with [occ-type = 1 and age > 25 and church = [church] of dying-
agent and not fisherman-caretaker? and not stay-at-home-dad?])

 if any? poss-travelers [
  ask poss-travelers [
   if not agent-found? [
   let num-fishermen count alive-agents with [boat-id = [boat-id] of myself and occ-type = 1]
   if num-fishermen > 2 [
    set occ-type 4
    let occ-part remainder occupation 100
    set occupation occ-part + 400
    set agent-found? true]
   ] ] ]
```

```
  report agent-found?
end

;;Data Collection and Display Update Methods

to update-daily-output
  tally
  draw-plots
  write-to-daily-file
end

to tally
  set num-susceptible count NI-agents with [disease-status = 0]
  set num-exposed count NI-agents with [disease-status = 1]
  set num-infectious count NI-agents with [disease-status = 2]
  set num-recovered count NI-agents with [disease-status = 3]
  set num-dead count ghosts
  set RD num-recovered + num-dead ;size of epidemic excluding orphans who have left the community
  set RDNsO RD + num-infected-orphans-gone ; size of epidemic including orphans who have left the
community
  set SRDO num-susceptible + RD + num-orphans-gone ; should equal pop-size if the epidemic concluded
by the time the simulation ended
end

to draw-plots
  set-current-plot "Epidemic Curve"
  set-current-plot-pen "Susceptible"
  plot num-susceptible
  set-current-plot-pen "Exposed"
  plot num-exposed
  set-current-plot-pen "Infectious"
  plot num-infectious
  set-current-plot-pen "Recovered"
  plot num-recovered
  set-current-plot-pen "Dead"
  plot num-dead
end

to write-to-daily-file
  file-open "DailyData.csv"
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ")  ; The Netlogo clock starts at tick 0. One tick is added in data recording so
that events in the simulation start at tick 1. For example, the first tick that the first case is infectious is
latent period + 1, i.e. tick 7 if the latent period is 6 days. This also ensures that the data recording is
consistent with the visualization.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
  file-type (word death-prob ", ")
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
  file-type (word first-case-occ ", ")
  file-type (word num-susceptible ", ")
```

```
  file-type (word count NI-agents with [newly-infected?] ", ")
  file-type (word num-exposed ", ")
  file-type (word num-infectious ", ")
  file-type (word num-recovered ", ")
  file-type (word count ghosts with [newly-dead?] ", ")
  file-type (word num-dead ", ")
  file-type (word num-infected-orphans-gone ", ")
  file-print (word num-orphans-gone ", ")
  file-close
end

to update-final-output
  write-to-cases-file
  write-to-final-file
end

to write-to-cases-file
  file-open "CasesData.csv"
  foreach sort-on [agt-id] NI-agents [
    ask ? [
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ") ; See comment above in the write-to-daily-file method.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
  file-type (word death-prob ", ")
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
  file-type (word first-case-occ ", ")
  file-type (word agt-id ", ")
  file-type (word dwelling ", ")
  file-type (word occupation ", ")
  file-type (word infector-id ", ")
  file-type (word infector-dwelling ", ")
  file-type (word infector-occ ", ")
  file-type (word time-infected ", ")
  file-type (word place-infected ", ")
  file-type (word time-died ", ")
  file-type (word place-died ", ")
  file-print (word time-leaves-village ", ")]]
  file-close
end

to write-to-final-file
  file-open "FinalData.csv"
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ") ; See comment above in the write-to-daily-file method.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
  file-type (word death-prob ", ")
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
```

```
  file-type (word first-case-occ ", ")
  file-type (word num-susceptible ", ")
  file-type (word num-recovered ", ")
  file-type (word num-dead ", ")
  file-type (word num-infected-orphans-gone ", ")
  file-type (word num-orphans-gone ", ")
  file-type (word RD ", ")
  file-type (word RDNsO ", ")
  file-print (word SRDO ", ")
  file-close
end
```

Social Network Model Code

```
;; Variable Declarations

globals [
  ;; Slider variables. Default values listed below reflect estimates for the 1918 influenza pandemic.
  ; latent-period  ; default value = 1 day or 6 ticks (from literature).
  ; infectious-period  ; default value = 3 days or 18 ticks (from literature).
  ; transmission-prob ; default value = .065 (estimated to achieve a target 30% attack rate, as observed in
Greenspond mortality data)
  ; death-prob ; default value = 0.0013 per tick (converts to about 7.3 deaths per 1000 over the course of
an epidemic, a value estimated from Greenspond mortality data)
  ; run-length ; default value = 600. The number of ticks a simulation should run

  first-case ; the node-id of the first infected case
  first-case-occ ; the occupation of the first infected case

  pop-size ; This variable is used for data recording purposes only and is set equal to the count of initial
nodes (called NI-nodes) at the start of a simulation
  num-susceptible num-exposed num-infectious num-recovered num-dead
  num-orphans-gone ; this is the number of orphans who can't find a caretaker and are adopted out of the
community
  num-infected-orphans-gone ; this is the number of orphans who are exposed, infectious or recovered
when they leave the community. They are included in tallies because they are essentially still part of the
community's epidemic
  RD RDNsO SRDO ; these are variables used for keeping tallies for data-recording. RD = recovered + dead
(size of epidemic excluding orphans who have left the community), RDNsO = RD + non-susceptible
orphans (size of epidemic including orphans who have left the community), SRDO= susceptible + RD + all
orphans regardless of disease status (confirms that the epidemic has concluded and should equal pop-
size)

  church1-id ; corresponds to the building-id of the respective church in the Netlogo Agent-Based Model
(hereafter referred to as the ABM) and the value in the node read-in file identifying church membership.
Value is initialized during setup.
  church2-id

  ; The following variables are the "base values" that contribute to the strength of different links. They are
used in code that changes the relationships among new caretakers, adopted children and/or their link-
neighbors upon adoption. Str = strength, DW = dwelling, HH = household.
```

Str-DW-SameHH Str-DW-DiffHH Str-Church1 Str-Church2

; The following variables are the strengths of links due to fishing between different occupational types. They may need to be deducted from or added to the overall strengths between two different nodes if one of them becomes a primary caretaker for children or if children are adopted into households assigned to different boats. The strengths are returned to previous values if a caretaker resumes its previous occupation. Note that the specific variables of interest, as well as their values, are closely tied to daily occupational activities for the study community of Newell's Island and need to be carefully considered if modifying this model for other communities or purposes. In the variable names, the numbers/abbreviated letters refer to the occ types of the two nodes involved in the link. "Same" means the two nodes are assigned to the same boat. "Adj" refers to boats whose IDs are sequential, i.e. the boats are adjacent to each other on the ABM map. No interactions are modeled between fishers assigned to different boats that are not adjacent to each other.

Str-Boat-Same00 Str-Boat-Same01 Str-Boat-Same02 Str-Boat-Same0FC Str-Boat-Same11 Str-Boat-Same12 Str-Boat-Same18 Str-Boat-Same1FC Str-Boat-Same22 Str-Boat-Same28 Str-Boat-Same2FC Str-Boat-Same88 Str-Boat-Same8FC Str-Boat-SameFCx2 Str-Boat-Adj00 Str-Boat-Adj01 Str-Boat-Adj02 Str-Boat-Adj0FC Str-Boat-Adj11 Str-Boat-Adj12 Str-Boat-Adj18 Str-Boat-Adj1FC Str-Boat-Adj22 Str-Boat-Adj28 Str-Boat-Adj2FC Str-Boat-Adj88 Str-Boat-Adj8FC Str-Boat-AdjFCx2

;The following variables are the strengths of links reflecting the proportion of time nodes of different occupational types are at home together during the day Monday-Friday. These values may need to be deducted from or added to the overall link strength between two nodes when occupational status changes due to caretaking for own or adopted children. The strength component for visiting other dwellings is likely not large enough to make a difference when occupations change. In the names, sameHH/diffHH refers to nodes who are in the same dwelling but same or different households. As above, the numbers/abbreviated letters refer to the occ types of the two nodes involved in the link.

Str-Both-Home00 Str-Both-Home02 Str-Both-Home07 Str-Both-Home09 Str-Both-Home0SAHD Str-Both-Home22 Str-Both-Home27 Str-Both-Home29 Str-Both-Home2SAHD Str-Both-Home77 Str-Both-Home79-DiffHH Str-Both-Home79-SameHH Str-Both-Home7SAHD Str-Both-Home99-DiffHH Str-Both-Home99-SameHH Str-Both-Home9SAHD-DiffHH Str-Both-Home9SAHD-SameHH Str-Both-HomeSAHDx2

; The following variables are the strengths of links reflecting the proportion of time nodes of different occupational types within the same family spend together on Saturdays (either at home or in visiting groups). These values may need to be deducted from or added to the overall link strength between two nodes when occupational status changes due to caretaking for own or adopted children. In the names, sameHH/diffHH refers to nodes who are in the same dwelling but same or different households. As above, the numbers/abbreviated letters refer to the occ types of the two nodes involved in the link. 8o and 8y divide the school-aged children into older and younger categories since 8o children move independently from their caretakers on Saturdays while the movement of 8y children is tied to their caretaker's movement some of the time.

Sat-00 Sat-02 Sat-03 Sat-07 Sat-08o Sat-08y Sat-09-DiffHH Sat-0SAHD Sat-0TC Sat-22 Sat-23 Sat-27 Sat-28o Sat-28y Sat-29 Sat-2SAHD Sat-2TC Sat-37 Sat-38o Sat-38y Sat-39 Sat-3SAHD Sat-77 Sat-78o Sat-78y Sat-79-DiffHH Sat-79-SameHH Sat-7SAHD Sat-7TC Sat-8o9 Sat-8oSAHD Sat-8oTC Sat-8y8o Sat-8y8y Sat-8y9 Sat-8ySAHD Sat-8yTC Sat-99-DiffHH Sat-99-SameHH Sat-9SAHD-DiffHH Sat-9SAHD-SameHH Sat-9TC Sat-SAHDx2 Sat-TCSAHD

; The following variables are multipliers to scale down strengths of links in order to account for the size of buildings in the ABM and thus the relative likelihood two individuals in the same building might actually

```
be von Neumann neighbors. These variables are primarily used during initialization of links as part of the setup method. See the Info tab for more details on how these multipliers are calculated.
  db-scale ; Averages the size of the scaling multipliers calculated for dwellings and boats. The read-in file of link strengths and the small strength components declared above use the individual building type multipliers when they are initially calculated. However, additional adjustments may be made to particular relationships during initialization and many of these links involve relatives or friends who could interact in either building type. Therefore, these additional adjustments use this average multiplier.
  school-scale
  ]

breed [NI-nodes NI-node]
breed [ghosts ghost]
breed [orphans orphan]

turtles-own [ ; The first 12 variables are read in from a file
  node-id
  residence  ; All nodes are set to 1 which corresponds to Newell's Island
  disease-status ; 0 = susceptible, 1 = exposed, 2 = infectious, 3 = recovered, 4 = dead
  dwelling ; The ID of a person's dwelling
  household ; The ID of a person's household. Multiple households per dwelling are possible.
  ext-family ; The ID of a person's extended family. Currently, all nodes are assigned to an extended family reflecting surname (husband's name for married women).
  sex ; male = 0, female = 1
  age
  church
  health-history ; Corresponds to a node's relative health status, designed to take into account different possible influences that may impact a node's outcome when faced with a potential disease-transmitting contact. This variable can range from -1 to 1, with -1 corresponding to a maximum negative impact (i.e., 100% reduction), 0 corresponding to no impact on health, and 1 corresponding to a maximum positive impact. All nodes are currently set to 0 because this variable is designed for future model versions.
  occupation ; a user-defined integer variable corresponding to a node's occupation. All nodes have been assigned a 3-digit occupation code. See the Info tab for more details on these specific occupation codes. Occupations refer to node behavior categories that relate to normal daily activities and thus influence the strength of contacts between two nodes.
  boat-id

  occ-type ; A single digit code referring to the node's general occupation category and corresponding to the first digit of the occupation value, e.g. 1 = fishermen, whereas an occupation of 102 = a fisherman assigned to boat 2.

  ; The following variables are used in identifying new caretakers for children whose parents or previous caretakers have died.
  children-under-five?
  caretaker-found?
  caretaker-node
  fisherman-caretaker? ; This variable is used to identify a fisherman caretaker who is not a stay home dad.
  stay-at-home-dad? ; This variable is used to identify a fisherman who is a caretaker of preschool-aged children.
  teacher-caretaker? ; This variable is used to identify a (male) teacher/clergy caretaker. Teachers and clergy may only adopt school-aged children living in the same dwelling.

  time-to-infectious ; Timer variable set equivalent to the latent period that starts running at the tick a node is infected
```

```
  time-to-recovery ; Timer variable set equivalent to the infectious period that starts running at the tick an
infected node becomes infectious
  time-infected ; Tick at which the node is infected
  time-leaves-village ; Tick at which a child is unable to find a caretaker and is adopted out of the
community
  time-died
  infector-id ; the node-id of the infecting node
  infector-occ ; the occupation of the infecting node
  infector-dwelling ; the ID of the infecting node's dwelling

  newly-infected?
  newly-infectious?
  newly-dead?
  step-completed?
  ]

NI-nodes-own [
  possible-new-cases
  possible-infectors
]



links-own [
  strength ; This variable ranges from 0 to 1.0 and reflects the weight of the link between two nodes. The
strength is based on how many time ticks two nodes might come into contact during a typical week,
taking into account such factors as shared households, occupations, churches, etc. The strength is also
scaled by the size of the potential location of contact. It will mediate the probability of transmission. See
the Info tab for details on how strengths are calculated.
  sibling? ; This variable identifies children (age <= 15) in the same household and is used during the
adoption process. Note that they might simply be dependent children living in the same household and
aren't necessarily biological siblings. These nodes will have the same relationship in any household they
live in together, so no changes in strength are needed if they are all adopted into a new household (the
normal situation with adoption). However, strengths between these children and other children in the
community, such as children already living in the new household, will probably need to change. The
purpose of this variable is to ensure that the siblings' links retain whatever strength they had while links
with other children change if necessary.
  affinity-code ; This variable refers to the different types of relationships that might receive an additional
small strength component to increase variability among different pairs with this relationship and/or
account for a closer relationship than the baseline strength would suggest, e.g. spouses. NOTE: These
codes are not currently used in the model and are intended for future versions.
  adjacent-increase? ; This variable keeps track of whether a strength component has been added to the
link between pairs of fishers who fish in adjacent boats. This prevents an additional increase when
children are adopted or when stay-at-home-dads return to fishing after the death of preschool-children.
]

;;Setup Methods

to setup
  clear-all
  ask patches [set pcolor gray + 2.5]
  initialize-link-variables
  import-network
```

```
  infect-first-case
  set pop-size count NI-nodes
  set num-infectious 0
  set num-recovered 0
  set num-dead 0
  set num-orphans-gone 0
  set num-infected-orphans-gone 0
  set RD 0
  set RDNsO 0
  set SRDO 0

  create-files
  reset-ticks
end

to import-network
  set-default-shape NI-nodes "circle"
  import-attributes
  layout-circle (sort NI-nodes) (max-pxcor - 1)
  import-links
  repeat 10 [
    layout-spring (turtles with [any? link-neighbors]) links 0.05 (world-width / (sqrt count turtles)) 50
  ]
end

to initialize-link-variables ; The values below are chosen to reflect as closely as possible the contact rates
that occur in the ABM. The process for determining strengths is explained in the Info tab. Rounding errors
are likely at the .001 level or smaller when these values are used to change strengths during the adoption
process. These errors are both unavoidable due to how the program stores numbers and acceptable since
they introduce some stochasticity but are unlikely to affect transmission probability much.
  set Str-DW-SameHH 0.11
  set Str-DW-DiffHH 0.106
  set Str-Church1 0.001
  set Str-Church2 0.002 ; Church 2 is slightly smaller in size, so the likelihood of transmission is slightly
larger.

  set Str-Boat-Same00 0.039
  set Str-Boat-Same01 0.049
  set Str-Boat-Same02 0.039
  set Str-Boat-Same0FC 0.049
  set Str-Boat-Same11 0.11
  set Str-Boat-Same12 0.059
  set Str-Boat-Same18 0.015
  set Str-Boat-Same1FC 0.11
  set Str-Boat-Same22 0.047
  set Str-Boat-Same28 0.008
  set Str-Boat-Same2FC 0.059
  set Str-Boat-Same88 0.012
  set Str-Boat-Same8FC 0.015
  set Str-Boat-SameFCx2 0.11
  set Str-Boat-Adj00 0.003
  set Str-Boat-Adj01 0.004
  set Str-Boat-Adj02 0.003
```

```
set Str-Boat-Adj0FC 0.004
set Str-Boat-Adj11 0.009
set Str-Boat-Adj12 0.005
set Str-Boat-Adj18 0.001
set Str-Boat-Adj1FC 0.009
set Str-Boat-Adj22 0.004
set Str-Boat-Adj28 0.001
set Str-Boat-Adj2FC 0.005
set Str-Boat-Adj88 0.001
set Str-Boat-Adj8FC 0.001
set Str-Boat-AdjFCx2 0.009

set Str-Both-Home00 0.025
set Str-Both-Home02 0.025
set Str-Both-Home07 0.03
set Str-Both-Home09 0.03
set Str-Both-Home0SAHD 0.032
set Str-Both-Home22 0.025
set Str-Both-Home27 0.03
set Str-Both-Home29 0.03
set Str-Both-Home2SAHD 0.032
set Str-Both-Home77 0.054
set Str-Both-Home79-DiffHH 0.054
set Str-Both-Home79-SameHH 0.071
set Str-Both-Home7SAHD 0.06
set Str-Both-Home99-DiffHH 0.054
set Str-Both-Home99-SameHH 0.071
set Str-Both-Home9SAHD-DiffHH 0.06
set Str-Both-Home9SAHD-SameHH 0.071
set Str-Both-HomeSAHDx2 0.071

set Sat-00 0.011
set Sat-02 0.006
set Sat-03 0.011
set Sat-07 0.011
set Sat-08o 0.002
set Sat-08y 0.01
set Sat-09-DiffHH 0.011
set Sat-0SAHD 0.012
set Sat-0TC 0.011
set Sat-22 0.005
set Sat-23 0.006
set Sat-27 0.006
set Sat-28o 0.001
set Sat-28y 0.006
set Sat-29 0.006
set Sat-2SAHD 0.006
set Sat-2TC 0.006
set Sat-37 0.011
set Sat-38o 0.002
set Sat-38y 0.01
set Sat-39 0.011
set Sat-3SAHD 0.012
```

```
  set Sat-77 0.011
  set Sat-78o 0.002
  set Sat-78y 0.01
  set Sat-79-DiffHH 0.011
  set Sat-79-SameHH 0.014
  set Sat-7SAHD 0.012
  set Sat-7TC 0.011
  set Sat-8o9 0.002
  set Sat-8oSAHD 0.002
  set Sat-8oTC 0.002
  set Sat-8y8o 0.002
  set Sat-8y8y 0.01
  set Sat-8y9 0.01
  set Sat-8ySAHD 0.01
  set Sat-8yTC 0.01
  set Sat-99-DiffHH 0.011
  set Sat-99-SameHH 0.014
  set Sat-9SAHD-DiffHH 0.012
  set Sat-9SAHD-SameHH 0.014
  set Sat-9TC 0.011
  set Sat-SAHDx2 0.014
  set Sat-TCSAHD 0.012

  set db-scale 0.2288
  set school-scale 0.0975

  set church1-id 25
  set church2-id 26
end

to infect-first-case
   ask one-of NI-nodes [  ; Randomly chooses one NI-node to be the first case.
 ; ask turtle X [ ; Chooses a specific NI-node to be the first case. If a random node with specific
characteristics is desired, the code can be changed accordingly. NOTE: when using "ask turtle," the node
must be identified by its who value, which is the node-id - 1
    set disease-status 1 ; "Exposed"
    set color yellow
    set time-to-infectious latent-period
    set num-susceptible count NI-nodes - 1
    set num-exposed 1

    ; The indicated values for the following variables allow the user to easily identify the first case in output
data
    set time-infected 0
    set infector-id 0
    set infector-occ 0
    set infector-dwelling 0
    set first-case node-id
    set first-case-occ occupation
   ]
end
```

```
; This procedure creates the nodes of the network and assigns their attributes by reading in a file that contains the 12 node-specific attributes listed above as turtles-own variables and indicated as input from file. It also sets the initial values of the additional turtles-own variables that are not read in.
to import-attributes
  file-open "NIAgents114Final.txt"
  ; The following code reads in all the data in the file. Each line of data contains the values for the first 12 attributes for a single node in the order listed below .
  while [not file-at-end?]
  [
    let items read-from-string (word "[" file-read-line "]") ; Items is a temporary list of variables read in as string but converted to the appropriate variable type. "Word" concatenates the brackets to the line being read in, because list arguments need to be in brackets (see Netlogo user manual)
    create-NI-nodes 1 [
      set node-id item 0 items
      set residence item 1 items
      set disease-status item 2 items
      set dwelling item 3 items
      set household item 4 items
      set ext-family item 5 items
      set sex item 6 items
      set age item 7 items
      set church item 8 items
      set health-history item 9 items
      set occupation item 10 items
      set boat-id item 11 items

      set occ-type floor (occupation / 100)  ;floor reports the largest integer less than or equal to input number

      set children-under-five? false
      set caretaker-found? false
      set caretaker-node nobody
      set fisherman-caretaker? false
      set stay-at-home-dad? false
      set teacher-caretaker? false

      set time-to-infectious latent-period
      set time-to-recovery infectious-period
      set time-infected -1
      set time-leaves-village -1
      set time-died -1
      set infector-id -1
      set infector-occ -1
      set infector-dwelling -1

      set newly-infected? false
      set newly-infectious? false
      set newly-dead? false
      set step-completed? false

      set label node-id
      set color green
    ] ]
```

```
 file-close
end

; This procedure reads in a file that contains all the links between nodes. The file is tab-delimited with 4
columns. In this model, the links are undirected. The first column contains the node-id of the node
originating the link. The second column is the node-id of the node on the other end of the link. The third
column is the strength of the link. The fourth column is the affinity-code described above under links-own
variables.
to import-links
 file-open "NILinks114Final.txt"
 while [not file-at-end?]
 [
  ; The following code reads a single line into a four-item list and uses the information in the list to create
the links
  let items read-from-string (word "[" file-read-line "]")
  ask get-node (item 0 items)  ; get-node is a reporter method that returns the node with the specified
node-id
  [create-link-with get-node (item 1 items)
    [set strength item 2 items
     set affinity-code item 3 items
    ] ] ]
 file-close

 ask links [
  ; The following code adds the church strength component to each link between members of the same
church.
  ask one-of both-ends [
   if church = [church] of other-end [
    ask link-with other-end[
     ifelse [church] of other-end = church1-id
      [set strength strength + Str-Church1]
      [set strength strength + Str-Church2]
     ] ] ]

  ; The adjacent-increase method called below adds a small strength component between pairs of fishers
who are assigned to boats/shore crews that are adjacent on the ABM map. Note that this method may
also be called within the "go" method in procedures related to adoption of children and thus it is not
solely a "setup" method.
  set adjacent-increase? false
  increase-adjacent

  ; The following code does not alter the strength of specific types of links. Rather, it initializes the sibling?
variable for all links as false. It then identifies node pairs that are siblings (or other dependent children)
assigned to the same household and sets that link's sibling? variable true. The actual strengths between
sibling nodes are among those read in from an external file at the beginning of this method.
  ask one-of both-ends [
   ask link-with other-end [set sibling? false]
   if age <= 15 and [age] of other-end <= 15 [
    if household = [household] of other-end [
     ask link-with other-end [set sibling? true]]
   ] ]

  if strength > 1 [set strength 1] ; The link strength is a proportion and should be kept between 0 and 1.
```

```
    if strength <= 0 [die] ; Links of strength 0 or less must die because even if the link is hidden, the nodes
still recognize it as a link, so every time they ask link-neighbor?, it returns true.
    color-links
  ]
 end

to create-files

  ; The next three blocks of code put headers at the top of new output files (one each for case, daily and
final data) and then the files are closed again, which must happen before a simulation begins. The process
of inserting headers only happens if the files don't exist already. If a file does exist, output data are just
appended to data from previous simulations without inserting headers again.
  if (not file-exists? "CasesData.csv")[
  file-open "CasesData.csv"
  file-type "Run Number,"
  file-type "Tick, "
  file-type "Population Size, "
  file-type "Transmission Probability, "
  file-type "Mortality Probability, "
  file-type "Latent Period, "
  file-type "Infectious Period, "
  file-type "First Case ID, "
  file-type "First Case Occ, "
  file-type "Node ID, "
  file-type "Node Dwelling, "
  file-type "Node Occupation, "
  file-type "Infector ID, "
  file-type "Infector Dwelling, "
  file-type "Infector Occupation, "
  file-type "Time Infected, "
  file-type "Time Died, "
  file-print "Time Leaves Village, "
  file-close]

  if (not file-exists? "DailyData.csv")[
  file-open "DailyData.csv"
  file-type "Run Number,"
  file-type "Tick, "
  file-type "Population Size, "
  file-type "Transmission Probability, "
  file-type "Mortality Probability, "
  file-type "Latent Period, "
  file-type "Infectious Period, "
  file-type "First Case ID, "
  file-type "First Case Occ, "
  file-type "Susceptible, "
  file-type "Newly Infected, "
  file-type "Exposed, "
  file-type "Infectious, "
  file-type "Recovered, "
  file-type "Newly Dead, "
  file-type "Total Dead, "
  file-type "Non-Susceptible Orphan Migrants, "
```

```
 file-print "Total Orphan Migrants, "
 file-close]

 if (not file-exists? "FinalData.csv")[
 file-open "FinalData.csv"
 file-type "Run Number,"
 file-type "Tick, "
 file-type "Population Size, "
 file-type "Transmission Probability, "
 file-type "Mortality Probability, "
 file-type "Latent Period, "
 file-type "Infectious Period, "
 file-type "First Case ID, "
 file-type "First Case Occ, "
 file-type "Susceptible, "
 file-type "Recovered, "
 file-type "Total Dead, "
 file-type "Non-Susceptible Orphan Migrants, "
 file-type "Total Orphan Migrants, "
 file-type "R+D (Final Size/No Orphans), "
 file-type "R+D+NsO (Final Size/Orphans), "
 file-print "S+R+D+O (Finish?), "
 file-close]
end

;;Step Methods

to go
 ask turtles[  ; the newly? variables reset here are for data recording purposes and to prevent multiple
transmissions (e.g. if a node is infected by another before it goes through the go method itself and before
disease variables are updated accordingly).
  if time-infected != ticks + 1[set newly-infected? false]
  set newly-dead? false
 ]

 ask NI-nodes[
  if (disease-status = 1 or disease-status = 2) [update-disease-status]

  ; The following code makes sets of NI-nodes that are linked to the calling NI-node and have the disease
status that results in a S-I pair. The calling NI-node then calls the transmit method appropriate to its own
status.
  if any? NI-nodes with [disease-status = 2][
   ifelse disease-status = 0
    [set possible-infectors (turtle-set NI-nodes with [disease-status = 2 and link-neighbor? myself])
     if any? possible-infectors [
      transmit-from (possible-infectors)]]
    [if disease-status = 2 [
      set possible-new-cases (turtle-set NI-nodes with [disease-status = 0 and link-neighbor? myself])
      if any? possible-new-cases [
       transmit-to (possible-new-cases)]]
     ] ]

  set step-completed? true
```

```
  ]

  ask ghosts [  ; Immediately after NI-nodes die, any caretakers must arrange for dependent children to be
reassigned to new caretakers. Any dying children need to determine whether they have surviving siblings
and if not, arrange for male caretakers to return to previous activities, e.g. fishing. Female caretakers
retain their occupational status throughout the rest of the simulation, even if all dependent children die.
     if newly-dead? [reassign-kids]
  ]
 ask turtles [
    set step-completed? false
    set newly-infectious? false] ; This value may change to true when update-disease-status is called above.
It is a check that allows infectious agents to survive and transmit at least one tick before dying

  update-daily-output

  ; The tick value (on the run-length global/slider) can and should be changed with different parameter
values to make sure the entire epidemic is included in data output
  if ticks + 1 = run-length [
    update-final-output
    stop]

  tick
end

;;Disease Methods

to update-disease-status ; An NI-node method called near the beginning of the go method. Depending on
their current disease status and the value of relevant timing variables, NI-nodes will transition to the next
disease status or reduce the time remaining for the current status (or die, with some probability, if they
are infectious). The durations of disease stages are equal for all NI-nodes.

  ; Susceptible NI-nodes do nothing

  ; Exposed nodes must check the value of time-to-infectious to see if they should become infectious this
time period.
  if disease-status = 1 [
    ifelse time-to-infectious = 0
      [set disease-status 2
       set newly-infectious? true
       set time-to-recovery infectious-period
       set color red]
      [set time-to-infectious time-to-infectious - 1]
    ] ; Closes IF

  ; Infectious nodes first check whether they will die this time period. If they survive, they must check the
value of time-to-recovery to see if they should recover this time period.
  if disease-status = 2 [
    if not newly-infectious? [
      let death-threshold random-float 1.0
      if death-threshold <= death-prob [kill-node]
      ]
```

```
  ifelse time-to-recovery = 0 and disease-status = 2 ; The ifelse statement includes the disease-status component so nodes who die this tick don't override changes made in kill-node
   [set disease-status 3
    set color violet]
   [set time-to-recovery time-to-recovery - 1]
  ]

  ; Recovered and dead NI-nodes do nothing.

end

to transmit-from [infectors-set]
 let susc-node self
 let prob random-float 1.0
 let local-strength 0
 ask infectors-set [
  ask link [who] of self [who] of susc-node [  ; Self refers to individuals in infectors-set
   set local-strength strength ; This is used to prevent accidentally changing strength and to make code below more efficient/clear.
   ]

  if (disease-status = 2 and prob <= transmission-prob * local-strength and not [newly-infected?] of susc-node) [
   ask susc-node [
    set disease-status 1
    set color yellow
    set time-to-infectious latent-period - 1
    set time-infected ticks + 1  ; The plus one is to correct the timing since ticks increment at the end of the go method and thus it is recording the previous value of ticks during the current go.
    set infector-id [node-id] of myself ; myself now refers to the member of infectors-set who called the above "ask susc-node".
    set infector-occ [occupation] of myself
    set infector-dwelling [dwelling] of myself
    set newly-infected? true
    ] ] ]
end

to transmit-to [new-cases-set]
 let infector-node self
 let prob random-float 1.0
 let local-strength 0
 ask new-cases-set [
  ask link [who] of self [who] of infector-node [  ; self is member of new-cases-set
   set local-strength strength  ; This is used to prevent accidentally changing strength and to make code below more efficient/clear.
   ]

  if (disease-status = 0 and prob <= transmission-prob * local-strength) [
   set disease-status 1
   set color yellow
   set time-to-infectious latent-period
   set time-infected ticks + 1  ; The plus one is to correct the timing since ticks increment at the end of the go method and thus it is recording the previous value of ticks during the current go.
```

```
   set infector-id [node-id] of infector-node
   set infector-occ [occupation] of infector-node
   set infector-dwelling [dwelling] of infector-node
   set newly-infected? true
   if step-completed? [
    set time-to-infectious time-to-infectious - 1
   ] ] ]
 end

;;Death Methods

to kill-node  ; this method is called by an NI-node at the time of death (as part of update-disease)
 set breed ghosts
 set shape "ghost"
 set size 2
 set disease-status 4
 set color white
 set newly-dead? true
 set time-died ticks + 1 ; as in the transmission methods above, the +1 needs to correct for how the go method keeps track of time
end

; The following method is called by a newly-dead ghost at the end of the go method. If the newly-dead ghost is a parent or caretaker of children under 15 years old, the children need to be assigned to a new caretaker. It is assumed that children who are orphaned always move into the household of the new caretaker which means that the caretakers themselves never move to new households. If the newly-dead ghost is a child, it needs to check to see if there are surviving siblings in the household and whether the caretaker, if male, can return to his previous activities, e.g. fishing. Female caretakers remain in their current occupation status even if there are no surviving children.

to reassign-kids

 set children-under-five? false
 let dying-node self

 ; Newly-dead ghosts who are mothers/female caretakers, fisherman-caretakers, SAHDs or teacher-caretakers need to see if they have any children that need to be reassigned to new caretakers
 if (occ-type = 0 or occ-type = 2 or occ-type = 7 or fisherman-caretaker? or stay-at-home-dad? or teacher-caretaker?) [
  let children (turtle-set NI-nodes with [age <= 15 and household = [household] of dying-node and link-neighbor? myself])
  if any? children [
   ask children [if age < 5 [ask dying-node [set children-under-five? true]]]
   ask one-of children [
    set caretaker-found? false
    set caretaker-node nobody
    find-same-household-caretaker (dying-node) ; the child first attempts to find a caretaker in the same household
    if not caretaker-found? [find-same-dwelling-caretaker (dying-node)]  ; the child then attempts to find a caretaker in another household in the same dwelling
    if not caretaker-found? [find-ext-family-caretaker (dying-node)] ; the child then attempts to find a caretaker in a different dwelling but in the same extended family as the dying caretaker
```

```
      if not caretaker-found?[find-any-caretaker (dying-node)]  ; the child finally attempts to find any
available caretaker. Since the other three methods failed, potential caretakers in this method live in a
different dwelling and are not part of the dying caretaker's extended family

   if caretaker-found? [
        ask caretaker-node [reassign-caretaker-links (dying-node)]] ; Once the new caretaker is identified, it
calls this method to change the strengths of its links with all other
      ; nodes, if necessary, to reflect its new occupation
      ifelse caretaker-found?
        [ask children [
          set caretaker-node [caretaker-node] of myself ; Myself refers to the child (the chosen one of the
entire group of siblings) who found the new caretaker; all children in the household need to have this
variable set to the new caretaker their sibling identified
          reassign-adopted-links dying-node caretaker-node] ; All children call this method to change the
strengths of their links with all other nodes, if necessary, to reflect possible changes in residence and
associated links
         ] ; closes if of ifelse caretaker-found?
        [ask children [ ; if no caretaker is found, the orphaned children leave the village
          set num-orphans-gone num-orphans-gone + 1
          if disease-status != 0 [set num-infected-orphans-gone num-infected-orphans-gone + 1]
          set time-leaves-village ticks + 1
          set breed orphans
          ask my-links [die]
          hide-turtle
          ] ; closes ask children
         ] ; closes else of ifelse caretaker-found?
       ] ; closes ask one-of children
     ] ; closes if any? children
   ] ; closes if dying-node is a caretaker

  ; Newly-dead ghosts who are kids <=15 need to check if there are any surviving siblings and the ages of
those children. If there are no siblings at all, the first block of code allows fisherman- and teacher-
caretakers to return to their previous status, but the change in status of stay-at-home-dads is delayed
until the next block of code. If there are no surviving siblings under 5 years of age (the second block of
code), stay-at-home-dads either become fisherman-caretakers (i.e. there are surviving school-aged
siblings) or return to non-caretaker fisherman status (i.e. there are no surviving siblings at all). When male
caretakers return to their previous status, it is only necessary to change link strengths for stay-at-home-
dads who return to fishing. All other occupations retained their regular behavior when they adopted older
children. Female caretakers do not return to previous occupations even if there are no surviving siblings.

  if age <= 15 [
    let siblings (turtle-set NI-nodes with [age <= 15 and household = [household] of myself and link-
neighbor? dying-node])
    let siblings-under-five (turtle-set NI-nodes with [age < 5 and household = [household] of myself and link-
neighbor? dying-node])

    if not any? siblings [
     if any? NI-nodes with [link-neighbor? dying-node and household = [household] of dying-node and sex =
0 and age > 15][
      ask NI-nodes with [link-neighbor? dying-node and household = [household] of dying-node and sex = 0
and age > 15][
        if teacher-caretaker? [set teacher-caretaker? false]
        if fisherman-caretaker? [set fisherman-caretaker? false]
```

```
     ] ] ]

  if not any? siblings-under-five [
   if any? NI-nodes with [link-neighbor? dying-node and household = [household] of dying-node and sex =
0 and age > 15][
    ask NI-nodes with [link-neighbor? dying-node and household = [household] of dying-node and sex = 0
and age > 15][
     if stay-at-home-dad? [
      set stay-at-home-dad? false
      restore-fishing-links]
     if any? siblings and occ-type = 1 [set fisherman-caretaker? true] ; closes if any? siblings. Teacher-
caretakers should not change this variable
     ] ; closes ask NI-nodes
    ] ; closes if any? NI-nodes
   ] ; closes if not any? <5
  ] ; closes age test

 ; All newly-dead ghosts remove their links when they die, and all remaining links are recolored to reflect
strength changes made during the reassignment process.
 ask my-links [die]
 ask links [
  if strength > 1 [set strength 1] ; The link strength is a proportion and should be kept between 0 and 1.
  if strength <= 0 [die] ; Links of strength 0 or less must die because even if the link is hidden, the nodes
still recognize it as a link, so every time they ask link-neighbor?, it returns true.
  color-links]
end

to find-same-household-caretaker [dead-node] ; This method is called by ONE child of a newly-dead
caretaker
 ; Create agent-set(s) of NI-nodes with matching household to be potential caretakers. Multiple sets are
used to prioritize, i.e. first 0/7, then 2/9 >15, then fishermen, then teachers/clergy. The last group will
only become caretakers for school-aged children.

 ; Note that there is only one agent assigned to occ-type 0 or 7 per household. Therefore, if one of these
agents dies, there will be none left in the household. If this method is called by a male caretaker, that
individual only became the caretaker because all the females had been exhausted. The ONLY time a dying
agent could produce any agents in the 0/7 category is when a female of occ-type 2, for example an older
daughter of a mother with occ-type 0, calls this method. In this scenario, the 0/7 test is used to identify if
there is already a caretaker in the household rather than to find a new/replacement caretaker.

 let child-node self

 let poss-07female-caretakers (turtle-set NI-nodes with [(occ-type = 0 or occ-type = 7) and household =
[household] of child-node and link-neighbor? child-node])

 let poss-29female-caretakers (turtle-set NI-nodes with [(occ-type = 2 or occ-type = 9) and age > 15 and
household = [household] of child-node and link-neighbor? child-node])

 let poss-male-caretakers (turtle-set NI-nodes with [occ-type = 1 and household = [household] of child-
node and link-neighbor? child-node])

 let poss-teacher-caretakers no-turtles
```

```
  if not [children-under-five?] of dead-node [set poss-teacher-caretakers (turtle-set NI-nodes with [occ-
type = 3 and sex = 0 and household = [household] of child-node and link-neighbor? child-node])]
   ; Poss-teacher-caretakers includes any resident male pastors who are also teachers (but does not
include traveling pastors, who are occ-type 4). Female teachers are not allowed to adopt children.

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set
caretaker-node to be the identified caretaker

  ifelse any? poss-07female-caretakers
    [ask one-of poss-07female-caretakers [
      ask child-node [
        set caretaker-node myself
        set caretaker-found? true]]] ; closes if of poss07
    [ifelse any? poss-29female-caretakers
      [ask one-of poss-29female-caretakers [
        ask child-node [
          set caretaker-node myself
          set caretaker-found? true]]] ; closes if of poss-29
      [ifelse any? poss-male-caretakers
        [ask one-of poss-male-caretakers [
          ask child-node [
            set caretaker-node myself
            set caretaker-found? true]]] ; closes if of male
        [if any? poss-teacher-caretakers [
          ask one-of poss-teacher-caretakers [
            ask child-node [
              set caretaker-node myself
              set caretaker-found? true]]]] ; closes else of male
      ] ; closes else of poss-29
    ]  ; closes else of poss-07
end

to find-same-dwelling-caretaker [dead-node]; This method is called by ONE child of a newly-dead
caretaker
    ; Create agent-set(s) of NI-nodes who live in the same dwelling as the newly-dead node, but are
assigned to a different household (SDDH). Multiple sets are used to prioritize, i.e. first 0/7, then 2, then
fishermen, then teachers/clergy. 9s over age 15 would never become caretakers, because they only live in
households with 7s who would be chosen first (and if the 7 dies, a 9 would become a 7). Male
teachers/clergy can only adopt school-aged kids.

    ; In the study community, all dwellings with multiple households consist of individuals who are
(apparently) closely related, so it is reasonable to assume that these SDDH individuals would be the first
choice caretakers after all SDSH adults have died. In communities where different households might
represent boarders or servants, this assumption becomes unrealistic. The code below may need to be
modified to exclude these people (i.e. be aware of the occupation codes, extended family, etc.) from
possible caretaker turtle-sets.

  let child-node self

  let poss-07female-caretakers (turtle-set NI-nodes with [(occ-type = 0 or occ-type = 7) and dwelling =
[dwelling] of child-node and household != [household] of child-node and link-neighbor? child-node])  ; The
"household != [household]" technically unnecessary since they failed the find-same-household method.
(Link-neighbor also technically unnecessary)
```

```
  let poss-2female-caretakers (turtle-set NI-nodes with [occ-type = 2 and dwelling = [dwelling] of child-node and household != [household] of child-node and link-neighbor? child-node])

  let poss-male-caretakers (turtle-set NI-nodes with [occ-type = 1 and dwelling = [dwelling] of child-node and household != [household] of child-node and link-neighbor? child-node])

  let poss-teacher-caretakers no-turtles
  if not [children-under-five?] of dead-node [set poss-teacher-caretakers (turtle-set NI-nodes with [occ-type = 3 and sex = 0 and dwelling = [dwelling] of child-node and household != [household] of child-node and link-neighbor? child-node])]

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set caretaker-node to be the identified caretaker
  ifelse any? poss-07female-caretakers
   [ask one-of poss-07female-caretakers [
      ask child-node [
        set caretaker-node myself
        set caretaker-found? true]]] ; closes if of poss07
   [ifelse any? poss-2female-caretakers
     [ask one-of poss-2female-caretakers [
        ask child-node [
          set caretaker-node myself
          set caretaker-found? true]]] ; closes if of poss2
     [ifelse any? poss-male-caretakers
       [ask one-of poss-male-caretakers [
         if any? other NI-nodes with [household = [household] of myself and occ-type = 1][ ; This segment of code ensures there is only one male caretaker in a household.
           ask other NI-nodes with [household = [household] of myself and occ-type = 1][
             if fisherman-caretaker? or stay-at-home-dad? [
               ask child-node [
                 set caretaker-node myself
                 set caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-existing fisherman caretaker in the selected household
         if not [caretaker-found?] of child-node[
           ask child-node [
             set caretaker-node myself
             set caretaker-found? true]]]] ; closes if of poss fishermen
       [if any? poss-teacher-caretakers [
         ask one-of poss-teacher-caretakers [
         if any? other NI-nodes with [household = [household] of myself and occ-type = 3][ ; This segment of code ensures there is only one teacher caretaker in a household.
           ask other NI-nodes with [household = [household] of myself and occ-type = 3][
             if teacher-caretaker? [
               ask child-node [
                 set caretaker-node myself
                 set caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-existing teacher-caretaker in the selected household
         if not [caretaker-found?] of child-node[
           ask child-node [
             set caretaker-node myself
             set caretaker-found? true]]]] ; closes if any? poss teacher
       ]; closes else of possfishermen
```

```
     ]; closes else of poss29
   ]; closes else of poss07

end

to find-ext-family-caretaker [dead-node]; This method is called by ONE child of a newly-dead caretaker
    ; Create agent-set(s) of NI-nodes who have some relationship (i.e. are members of the same extended
family) to the newly-dead node but aren't in the same dwelling. Presence or strengths of links are not
used here, because it is possible that links may be stronger between unrelated individuals than they are
between related individuals who happen not to engage in daily behavior, such as fishing, together. For
example, two 7 agents have relatively weak strengths with each other but may be sisters/sisters-in-law. It
is likely that children would be adopted by close relatives, even if that kinship is not reflected in the
strength of links prior to adoption.

    ; Multiple sets are used to prioritize, i.e. first 0/7, then 2, then fishermen. As above, 9s over age 15
would have switched to occ-type 7 earlier if needed to be caretakers and would never become caretakers
while assigned to occ-type 9. Unlike the previous methods, teachers/clergy are not considered potential
caretakers; it is assumed that these agents will only step in to adopt children from their own dwelling.

  let child-node self

  let poss-07female-caretakers (turtle-set NI-nodes with [(occ-type = 0 or occ-type = 7) and dwelling !=
[dwelling] of child-node and ext-family = [ext-family] of dead-node]) ; The dwelling test here is technically
unnecessary because the child will have failed the same or other household (same dwelling) tests above.

  let poss-2female-caretakers (turtle-set NI-nodes with [occ-type = 2 and dwelling != [dwelling] of child-
node and ext-family = [ext-family] of dead-node])

  let poss-male-caretakers (turtle-set NI-nodes with [occ-type = 1 and dwelling != [dwelling] of child-node
and ext-family = [ext-family] of dead-node])

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set
caretaker-node to be the identified caretaker
  ifelse any? poss-07female-caretakers
   [ask one-of poss-07female-caretakers [
      ask child-node [
        set caretaker-node myself
        set caretaker-found? true]]] ; closes if of poss07
   [ifelse any? poss-2female-caretakers
     [ask one-of poss-2female-caretakers [
        ask child-node [
          set caretaker-node myself
          set caretaker-found? true]]] ; closes if of poss2
     [if any? poss-male-caretakers [
       ask one-of poss-male-caretakers [
         if any? other NI-nodes with [household = [household] of myself and occ-type = 1][ ; This segment of
code ensures there is only one male caretaker in a household.
           ask other NI-nodes with [household = [household] of myself and occ-type = 1][
             if fisherman-caretaker? or stay-at-home-dad? [
               ask child-node [
                 set caretaker-node myself
                 set caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-existing
fisherman caretaker in the selected household
```

```
        if not [caretaker-found?] of child-node[
        ask child-node [
          set caretaker-node myself
          set caretaker-found? true]]]] ; closes if any poss male
      ]; closes else of poss2
    ]; closes else of poss07
end

to find-any-caretaker [dead-node]; This method is called by ONE child of a newly-dead caretaker
    ; Create agent-set(s) of NI-nodes who did not meet the criteria in previous methods, i.e. they live in a different dwelling and are not part of the dying caretaker's extended family. Multiple sets are used to prioritize, i.e. first 0/7, then 2, then males. 9s over age 15 would never become caretakers, because they only live in households with 7s who would be chosen first (and if the 7 dies, a 9 would become a 7). As with the previous method, teachers/clergy are not allowed to adopt in this scenario.

  let child-node self

  let poss-07female-caretakers (turtle-set NI-nodes with [(occ-type = 0 or occ-type = 7) and dwelling != [dwelling] of child-node and ext-family != [ext-family] of dead-node])

  let poss-2female-caretakers (turtle-set NI-nodes with [occ-type = 2 and dwelling != [dwelling] of child-node and ext-family != [ext-family] of dead-node])

  let poss-male-caretakers (turtle-set NI-nodes with [occ-type = 1 and dwelling != [dwelling] of child-node and ext-family != [ext-family] of dead-node])

  ; We are assuming that teachers/clergy will step in only to adopt children from their own dwelling.

  ; ifelse loops checking if sets are empty. If any caretakers are found, set caretaker-found? true and set caretaker-node to be the identified caretaker
  ifelse any? poss-07female-caretakers
   [ask one-of poss-07female-caretakers [
    ask child-node [
      set caretaker-node myself
      set caretaker-found? true]]] ; closes if of poss-07
   [ifelse any? poss-2female-caretakers
    [ask one-of poss-2female-caretakers [
      ask child-node [
        set caretaker-node myself
        set caretaker-found? true]]]
    [if any? poss-male-caretakers [
      ask one-of poss-male-caretakers [
        if any? other NI-nodes with [household = [household] of myself and occ-type = 1][ ; This segment of code ensures there is only one male caretaker in a household.
          ask other NI-nodes with [household = [household] of myself and occ-type = 1][
            if fisherman-caretaker? or stay-at-home-dad? [
              ask child-node [
                set caretaker-node myself
                set caretaker-found? true]]]] ; closes if any? test that checks whether there's a pre-existing fisherman caretaker in the selected household
        if not [caretaker-found?] of child-node[
        ask child-node [
          set caretaker-node myself
```

```
          set caretaker-found? true]]]] ;closes if any? fishermen
      ] ; closes else of poss-29
    ] ; closes else of poss-07
end

to reassign-caretaker-links [dead-node]  ; called by the new caretaker to reset strengths of links between it and all its link-neighbors reflecting new occupation/role. As mentioned above, the specific values and variables that change are tied to daily activity schedules for different types of occupations and how often such pairs would come into contact with each other during these activities.
  let ct-new-occ [occ-type] of dead-node
  let ct-dwelling dwelling
  let ct-household household
  let ct-who who
  let ct-boat boat-ID

   ; Dying node caretaker occ-types can only be 0, 2, 7, stay-at-home dad (SAHD), fisherman-caretaker or teacher-caretaker. Most adults can adopt children although there are specific situations where they can't (example: traveling clergy can't adopt at all, and resident teachers/clergy only adopt within their dwelling.) Depending on the age of the children and the previous and new occ-type of the new caretaker, strength components for fishing and/or staying at home need to be adjusted.

;;Occ-Type 0;

  ; A female of occ-type 0 adopting children from another 0, a 2, a teacher-caretaker or a fisherman-caretaker will remain an occ-type 0 and so no adjustments are needed.

  ; A female of occ-type 0 taking over for a node with occ-type 7 or a stay-at-home-dad will change to occ-type 7 and needs to reduce her strength by the appropriate fishing components and increase by the appropriate components for staying home activities. In this situation, there is no change in Saturday activities.
  if occ-type = 0 and (ct-new-occ = 7 or [stay-at-home-dad?] of dead-node)[
    if any? NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling] [ ; only individuals living in the same dwelling need to increase staying at home strengths
      ask NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling] [
        if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home07 - Str-Both-Home00)]]
        if occ-type = 2 [ask link who ct-who [set strength strength + (Str-Both-Home27 - Str-Both-Home02)]]
        if occ-type = 7 and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home77 - Str-Both-Home07)]]
        if occ-type = 9 and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home79-DiffHH - Str-Both-Home09)]]
        if stay-at-home-dad? and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home7SAHD - Str-Both-Home0SAHD)]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
    if any? NI-nodes with [link-neighbor? myself and boat-ID = ct-boat] [ ; individuals fishing in the same boat need to decrease fishing strengths
      ask NI-nodes with [link-neighbor? myself and boat-ID = ct-boat] [
        if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same00]]
        if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [set strength strength - Str-Boat-Same01]]
        if occ-type = 2 [ask link who ct-who [set strength strength - Str-Boat-Same02]]
```

```
    if fisherman-caretaker? and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same0FC]]
   ] ; closes ask NI-nodes
  ] ; closes if any?
  if any? NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][ ; individuals fishing in adjacent boats need to decrease fishing strengths
   ask NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
    if occ-type = 0 [ask link who ct-who [
      set strength strength - Str-Boat-Adj00
      set adjacent-increase? false]]
    if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [
      set strength strength - Str-Boat-Adj01
      set adjacent-increase? false]]
    if occ-type = 2 [ask link who ct-who [
      set strength strength - Str-Boat-Adj02
      set adjacent-increase? false]]
    if fisherman-caretaker? [ask link who ct-who [
      set strength strength - Str-Boat-Adj0FC
      set adjacent-increase? false]]
   ] ;closes ask NI-nodes
  ]; closes if any?
 ] ; closes if occ-type = 0...

 ;;Occ-Type 1

 ; A male of occ-type 1 who is not already taking care of kids and is now taking over for a node with occ-type 7 or a stay-at-home-dad will change to a stay-at-home-dad and needs to reduce his strength by the appropriate fishing components and increase by the appropriate components for staying home or Saturday activities.
 if (occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad?) and (ct-new-occ = 7 or [stay-at-home-dad?] of dead-node) [
  if any? NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][ ; only individuals living in the same dwelling need to increase staying at home and Saturday strengths
   ask NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
    if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength + Str-Both-Home0SAHD + Sat-0SAHD]]
    if occ-type = 2 [ask link who ct-who [set strength strength + Str-Both-Home2SAHD + Sat-2SAHD]]
    if occ-type = 3 and not teacher-caretaker? [ask link who ct-who [set strength strength + Sat-3SAHD]]
    if occ-type = 7 and household != ct-household [ask link who ct-who [set strength strength + Str-Both-Home7SAHD + Sat-7SAHD]]
    if occ-type = 8 and age < 10 [ask link who ct-who [set strength strength + Sat-8ySAHD]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength + Sat-8oSAHD]]
    if occ-type = 9 [
     ifelse household = ct-household
      [ask link who ct-who [set strength strength + Str-Both-Home9SAHD-SameHH + Sat-9SAHD-SameHH]]
      [ask link who ct-who [set strength strength + Str-Both-Home9SAHD-DiffHH + Sat-9SAHD-DiffHH]]]
    if stay-at-home-dad? and household != ct-household [ask link who ct-who [set strength strength + Str-Both-HomeSAHDx2 + Sat-SAHDx2]]
    if teacher-caretaker? and household != ct-household [ask link who ct-who [set strength strength + Sat-TCSAHD]]
   ] ; closes ask NI-nodes
  ] ; closes if any?
```

```
  if any? NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][ ; individuals fishing in the same boat need to decrease fishing strengths
   ask NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
    if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same01]]
    if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [set strength strength - Str-Boat-Same11]]
    if occ-type = 2 [ask link who ct-who [set strength strength - Str-Boat-Same12]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength - Str-Boat-Same18]]
    if fisherman-caretaker? and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same1FC]]
   ] ; closes ask NI-nodes
  ] ; closes if any?
  if any? NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][ ; individuals fishing in adjacent boats need to decrease fishing strengths
   ask NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
    if occ-type = 0 [ask link who ct-who [
      set strength strength - Str-Boat-Adj01
      set adjacent-increase? false]]
    if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [
      set strength strength - Str-Boat-Adj11
      set adjacent-increase? false]]
    if occ-type = 2 [ask link who ct-who [
      set strength strength - Str-Boat-Adj12
      set adjacent-increase? false]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [
      set strength strength - Str-Boat-Adj18
      set adjacent-increase? false]]
    if fisherman-caretaker? [ask link who ct-who [
      set strength strength - Str-Boat-Adj1FC
      set adjacent-increase? false]]
   ]; closes ask NI-nodes
  ]; closes if any?
 ] ; closes if occ-type = 1...

 ; A male of occ-type 1 who is currently a fisherman-caretaker and is taking over for an occ-type 7 or a stay-at-home-dad will change to a stay-at-home-dad and needs to reduce his strength by the appropriate fishing components and increase by the appropriate components for staying home or Saturday activities. Note that this is very similar to the above block but it is kept separate due to slight differences and in case we change behavior for fisherman-caretakers.
 if fisherman-caretaker? and (ct-new-occ = 7 or [stay-at-home-dad?] of dead-node) [
  if any? NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][  ; only individuals living in the same dwelling need to increase staying at home and Saturday strengths
   ask NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
    if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength + Str-Both-Home0SAHD + Sat-0SAHD]]
    if occ-type = 2 [ask link who ct-who [set strength strength + Str-Both-Home2SAHD + Sat-2SAHD]]
    if occ-type = 3 and not teacher-caretaker? [ask link who ct-who [set strength strength + Sat-3SAHD]]
    if occ-type = 7 and household != ct-household [ask link who ct-who [set strength strength + Str-Both-Home7SAHD + Sat-7SAHD]]
    if occ-type = 8 and age < 10 [ask link who ct-who [set strength strength + Sat-8ySAHD]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength + Sat-8oSAHD]]
```

```
        if occ-type = 9 and household = ct-household [ask link who ct-who [set strength strength + Str-Both-Home9SAHD-DiffHH + Sat-9SAHD-DiffHH]]
        ; There should be no 9s < 5 in the same household as a FC - if there were, he would have been set to a SAHD to begin with. Similarly, there should be no 9s > 15 because if there were, they would have been picked to be the new caretaker first.
        if stay-at-home-dad? and household != ct-household [ask link who ct-who [set strength strength + Str-Both-HomeSAHDx2 + Sat-SAHDx2]]
        if teacher-caretaker? and household != ct-household [ask link who ct-who [set strength strength + Sat-TCSAHD]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
    if any? NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][ ; individuals fishing in the same boat need to decrease fishing strengths
      ask NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
        if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same0FC]]
        if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [set strength strength - Str-Boat-Same1FC]]
        if occ-type = 2 [ask link who ct-who [set strength strength - Str-Boat-Same2FC]]
        if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength - Str-Boat-Same8FC]]
        if fisherman-caretaker? and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-SameFCx2]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
    if any? NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][ ; individuals fishing in adjacent boats need to decrease fishing strengths
      ask NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
        if occ-type = 0 [ask link who ct-who [
            set strength strength - Str-Boat-Adj0FC
            set adjacent-increase? false]]
        if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [
            set strength strength - Str-Boat-Adj1FC
            set adjacent-increase? false]]
        if occ-type = 2 [ask link who ct-who [
            set strength strength - Str-Boat-Adj2FC
            set adjacent-increase? false]]
        if occ-type = 8 and age >= 10 [ask link who ct-who [
            set strength strength - Str-Boat-Adj8FC
            set adjacent-increase? false]]
        if fisherman-caretaker? [ask link who ct-who [
            set strength strength - Str-Boat-AdjFCx2
            set adjacent-increase? false]]
      ]; closes ask NI-nodes
    ]; closes if any?
  ] ; closes if occ-type = 1...

  ; A male of occ-type 1 adopting children from a 0, a 2, a teacher-caretaker or a fisherman-caretaker will become OR remain a fisherman-caretaker, so his behavior will not change and no adjustments are needed. Similarly, a stay-at-home-dad adopting additional children will remain this type of caretaker regardless of the ages of any new children, so no changes are made. Note fisherman-caretakers and stay-at-home-dads retain occ-type 1 when they add these designations.

;;Occ-Type 2
```

```
  ; A female of occ-type 2 taking over for a node with occ-type 0 or a fisherman-caretaker or a teacher-caretaker will change to occ-type 0 and needs to adjust her fishing strength component to reflect her reduced time fishing and increase the strength component for Saturday activities. She does not need to change the strength of other daily activities.
  if occ-type = 2 and (ct-new-occ = 0 or [fisherman-caretaker?] of dead-node or [teacher-caretaker?] of dead-node)[
    if any? NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
      ask NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
        if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength + (Sat-00 - Sat-02)]]
        if occ-type = 2 [ask link who ct-who [set strength strength + (Sat-02 - Sat-22)]]
        if occ-type = 3 and not teacher-caretaker? [ask link who ct-who [set strength strength + (Sat-03 - Sat-23)]]
        if occ-type = 7 and household != ct-household [ask link who ct-who [set strength strength + (Sat-07 - Sat-27)]]
        if occ-type = 8 and age < 10 [ask link who ct-who [set strength strength + (Sat-08y - Sat-28y)]]
        if occ-type = 9 and household != ct-household [ask link who ct-who [set strength strength + (Sat-09-DiffHH - Sat-29)]]
        if stay-at-home-dad? and household != ct-household [ask link who ct-who [set strength strength + (Sat-0SAHD - Sat-2SAHD)]]
        if teacher-caretaker? and household != ct-household [ask link who ct-who [set strength strength + (Sat-0TC - Sat-2TC)]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
    if any? NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
      ask NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
        if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [set strength strength - (Str-Boat-Same12 - Str-Boat-Same01)]]
        if occ-type = 2 [ask link who ct-who [set strength strength - (Str-Boat-Same22 - Str-Boat-Same02)]]
        if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength - Str-Boat-Same28]]
        if fisherman-caretaker? and household != ct-household [ask link who ct-who [set strength strength - (Str-Boat-Same2FC - Str-Boat-Same0FC)]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
    if any? NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
      ask NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
        if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [
          set strength strength - (Str-Boat-Adj12 - Str-Boat-Adj01)]]  ; Note that increase-adjacent? is not set to false, because a strength value remains on these links
        if occ-type = 2 [ask link who ct-who [
          set strength strength - (Str-Boat-Adj22 - Str-Boat-Adj02)]]
        if occ-type = 8 and age >= 10 [ask link who ct-who [
          set strength strength - Str-Boat-Adj28]]
        if fisherman-caretaker? [ask link who ct-who [
          set strength strength - (Str-Boat-Adj2FC - Str-Boat-Adj0FC)]]
      ]; closes ask NI-nodes
    ]; closes if any?
  ] ; closes if occ-type = 2...

  ; A female of occ-type 2 taking over for a node with occ-type 7 or a stay-at-home-dad will become a 7 and needs to reduce her strength by the appropriate fishing components and increase by the appropriate components for staying home and Saturday activities.
```

```
 if occ-type = 2 and (ct-new-occ = 7 or [stay-at-home-dad?] of dead-node)[
  if any? NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
   ask NI-nodes with [link-neighbor? myself and dwelling = ct-dwelling][
    if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home07 - Str-Both-Home02) + (Sat-07 - Sat-02)]]
    if occ-type = 2 [ask link who ct-who [set strength strength + (Str-Both-Home27 - Str-Both-Home22) + (Sat-27 - Sat-22)]]
    if occ-type = 3 and not teacher-caretaker? [ask link who ct-who [set strength strength + (Sat-37 - Sat-23)]]
    if occ-type = 7 and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home77 - Str-Both-Home27) + (Sat-77 - Sat-27)]]
    if occ-type = 8 and age < 10 [ask link who ct-who [set strength strength + (Sat-78y - Sat-28y)]]
    if occ-type = 9 [
     ifelse household = ct-household
      [ask link who ct-who [set strength strength + (Str-Both-Home79-SameHH - Str-Both-Home29) + (Sat-79-SameHH - Sat-29)]]
      [ask link who ct-who [set strength strength + (Str-Both-Home79-DiffHH - Str-Both-Home29) + (Sat-79-DiffHH - Sat-29)]]]
    if stay-at-home-dad? and household != ct-household [ask link who ct-who [set strength strength + (Str-Both-Home7SAHD - Str-Both-Home2SAHD) + (Sat-7SAHD - Sat-2SAHD)]]
    if teacher-caretaker? and household != ct-household [ask link who ct-who [set strength strength + (Sat-7TC - Sat-2TC)]]
   ] ; closes ask NI-nodes
  ] ; closes if any?
  if any? NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
   ask NI-nodes with [link-neighbor? myself and boat-ID = ct-boat][
    if occ-type = 0 and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same02]]
    if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [set strength strength - Str-Boat-Same12]]
    if occ-type = 2 [ask link who ct-who [set strength strength - Str-Boat-Same22]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [set strength strength - Str-Boat-Same28]]
    if fisherman-caretaker? and household != ct-household [ask link who ct-who [set strength strength - Str-Boat-Same2FC]]
   ] ; closes ask NI-nodes
  ] ; close if any?
  if any? NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
   ask NI-nodes with [link-neighbor? myself and (boat-id + 1 = ct-boat or boat-id - 1 = ct-boat)][
    if occ-type = 0 [ask link who ct-who [
      set strength strength - Str-Boat-Adj02
      set adjacent-increase? false]]
    if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who ct-who [
      set strength strength - Str-Boat-Adj12
      set adjacent-increase? false]]
    if occ-type = 2 [ask link who ct-who [
      set strength strength - Str-Boat-Adj22
      set adjacent-increase? false]]
    if occ-type = 8 and age >= 10 [ask link who ct-who [
      set strength strength - Str-Boat-Adj28
      set adjacent-increase? false]]
    if fisherman-caretaker? [ask link who ct-who [
      set strength strength - Str-Boat-Adj2FC
      set adjacent-increase? false]]
```

```
    ]; closes ask NI-nodes
   ]; closes if any?
  ] ; closes if occ-type = 2

;;Other Occ-Types

  ; A teacher/clergy of occ-type 3 can only take over for nodes with no young children (i.e. nodes of occ-type 0, teacher-caretakers or fisherman-caretakers) within their own dwelling. The new caretakers do not change their behavior when they adopt, so no strength adjustments are necessary. Note that teacher-caretakers retain occ-type 3.

  ; A female of occ-type 7 will retain this status to continue caring for the pre-school children already in her care regardless of the age(s) of the newly-adopted children and so no strength adjustments are necessary.

  ; A female of occ-type 9 will only be a potential replacement for caretakers in the same household as her (see notes in the find XX caretaker methods). An individual taking over for a node with occ-type 7 or a stay-at-home-dad will change to occ-type 7. 7s and 9s have effectively the same relationships to everyone else in the community and so no strength adjustments are required. A female of occ-type 9 will never take over for a 0, 2, fisherman-caretaker or teacher-caretaker because 9s over age 15 are only found in households with young children. The 9s are aides to the 7s in these households, and these 7s would be chosen as the priority caretaker by a newly-adopted child. If the 7 dies, a 9 would become the new 7. Note that in the NI population, there are no 9s > 15 years old anyway.

  ; Following completion of the link strength adjustments, the new caretaker needs to change its occupation identification variables to reflect its new status.

  if occ-type != 3 and occ-type != 7 and not stay-at-home-dad? [ ; these nodes do not change their occupation variables when they adopt new or additional children
    ifelse sex = 1  ; new caretaker is female
      [ifelse [sex] of dead-node = 0 ; previous caretaker is male
        ; If a 0, 2 or 9 female is taking over caretaking duties for a dad with children under five, she needs to become occ-type 7. Otherwise, if the children are all school-aged, she
        ; stays or becomes occ-type 0.
        [ifelse [stay-at-home-dad?] of dead-node
          [set occ-type 7
           let occ-part remainder occupation 100
           set occupation occ-part + 700] ; closes if stayathomedad?
          [set occ-type 0
           let occ-part remainder occupation 100
           set occupation occ-part]]; closes else stayathomedad and if sex of dying node
        [; if a 0, 2 or 9 female is taking over caretaking duties from another female, she needs to be set to the same occupation as the original caretaking female but with her own fishing boat assignment. The only time this would not be the case is if a 0 is taking over for a 2; this woman would need to remain a 0 because she may still have younger (5-9 year old) children in her care.
         ifelse (occ-type = 0 and [occ-type] of dead-node = 2)
           [ ; do nothing.]
           [set occ-type [occ-type] of dead-node
            let occ-part remainder occupation 100
            set occupation occ-part + occ-type * 100] ; closes else of occ-type 0/2
        ] ; closes else sex of dying node
       ] ; closes if (new caretaker is female)
```

```
      ; If the new caretaker is a fisherman (the only male occ-type that would be considered here), he must
become a stay-at-home dad if there are kids < 5. These males will set a Boolean variable true reflecting
their appropriate changes but otherwise retain their occupation codes of 1XX.
      [ifelse [children-under-five?] of dead-node
        [set stay-at-home-dad? true
         set fisherman-caretaker? false]
        [set fisherman-caretaker? true]
       ] ; closes else (new caretaker is male)
     ] ; closes if occ-type

  if occ-type = 3 and not [children-under-five?] of dead-node [ ; Teachers who become caretakers (to
school-aged children only) don't change their occupation variables but do need to change a boolean
reflecting their new status.
    set teacher-caretaker? true]
end

to reassign-adopted-links  [dead-node new-caretaker] ; This is called by all dependent children of a newly-
dead caretaker

  let adoptee self
  let adoptee-who who

  ; First, the older children need to check to see if their assigned boat and associated links should be
changed.

  if age >= 10 [check-boat (new-caretaker)]

  ; Second, all children check to see if they've moved into a new household. If they are adopted by a new
caretaker in the same household, the child-caretaker link is the only link that needs to be changed, and
this change occurs during reassign-caretaker-links. Children adopted into new households (same or new
dwellings) will first create a link with the new caretaker and all members of the new household (if
necessary), and then call reassign-household-links where they will adjust all these link strengths as
needed.
  if household != [household] of new-caretaker [
    ask NI-nodes with [household = [household] of new-caretaker] [if not link-neighbor? adoptee [
        create-link-with adoptee [
          set sibling? false
          set adjacent-increase? false]]]
    reassign-household-links (new-caretaker)
    ]

  ; The following block of code identifies any children already living in the new household and sets them to
be "siblings" of the adopted child. This prevents any errors in changing link strengths if all children are
adopted into another household in the future.
  if any? NI-nodes with [link-neighbor? adoptee and household = [household] of adoptee and age <= 15][
    ask NI-nodes with [link-neighbor? adoptee and household = [household] of adoptee and age <= 15][
      ask link who adoptee-who [if not sibling? [set sibling? true]]
    ] ]
end

to check-boat [new-caretaker] ; this method is called by older children who fish on Saturdays. If they are
adopted into a household with a different boat assignment, they switch to that boat and need to adjust
strength components accordingly.
```

```
  let fisherkid self
  let fisherkid-who who
  let adopted-household [household] of new-caretaker
  let adopted-boat [boat-ID] of new-caretaker
  let new-boat? false
  let old-boat boat-id

 ; The children test to see if the boat associated with the new caretaker is a different boat than their current assignment. Note that regardless of whether they need to change boats, there may be no surviving adults who fish in that boat, for example if the new caretaker is a 3 or 7 and no other fishers are in the crew. Historical evidence suggests that some children were known to work independently in unusual, extreme situations. Further, because model simulations represent a short-term timeframe, and because the "boat" activity does not differentiate between shore duty and actual fishing, this simplification is acceptable.
  if boat-id != [boat-id] of new-caretaker [
      set new-boat? true
      set boat-id [boat-id] of new-caretaker
      set occupation occ-type * 100 + boat-ID
    ]

  ; The children then subtract fishing strength components from any surviving crewmembers in the old boat. For example, there might be fishermen in the same boat who live in different dwellings, but the children get adopted into an alternate dwelling because it has a surviving adult female who would be the priority choice. They also subtract fishing strength components from links with any fishers assigned to boats adjacent to the old boat.
  if new-boat? [
    if any? NI-nodes with [link-neighbor? fisherkid and boat-ID = old-boat][
      ask NI-nodes with [link-neighbor? fisherkid and boat-ID = old-boat] [
        if occ-type = 1 and not stay-at-home-dad? and not fisherman-caretaker? [ask link who fisherkid-who [set strength strength - Str-Boat-Same18]]
        if occ-type = 2 [ask link who fisherkid-who [set strength strength - Str-Boat-Same28]]
        if occ-type = 8 and age >= 10 [ask link who fisherkid-who [if not sibling? [set strength strength - Str-Boat-Same88]]]
        if fisherman-caretaker? [ask link who fisherkid-who [set strength strength - Str-Boat-Same8FC]]
        ]] ; closes ask NI-nodes and if any?

    if any? NI-nodes with [link-neighbor? fisherkid and (boat-id + 1 = old-boat or boat-id - 1 = old-boat)] [
      ask NI-nodes with [link-neighbor? fisherkid and (boat-id + 1 = old-boat or boat-id - 1 = old-boat)] [
        if occ-type = 1 and not stay-at-home-dad? and not fisherman-caretaker? [ask link who fisherkid-who [
          if adjacent-increase? and not sibling? [ ; These two tests prevent multiple deductions to the same link. For example, the adjacent-increase? boolean may be set to false when new caretakers adjust their fishing behavior during the reassign-caretaker-links method. Sibling concerns are described in more detail below. While both tests might not be necessary for specific occ-types, they are included as fail-safes.
            set strength strength - Str-Boat-Adj18
            set adjacent-increase? false]]]
        if occ-type = 2 [ask link who fisherkid-who [
          if adjacent-increase? and not sibling? [
            set strength strength - Str-Boat-Adj28
            set adjacent-increase? false]]]
        if occ-type = 8 and age >= 10 [ask link who fisherkid-who [
          if adjacent-increase? and not sibling? [
            set strength strength - Str-Boat-Adj88
```

```
      set adjacent-increase? false]]]
    if fisherman-caretaker? [ask link who fisherkid-who [
     if adjacent-increase? and not sibling? [
      set strength strength - Str-Boat-Adj8FC
      set adjacent-increase? false]]]
   ]] ; closes ask NI-nodes and if any?

 ; The children then add the appropriate strength components to links with new crewmembers. Finally, the children call the increase-adjacent procedure to identify any fishers in boats adjacent to the new boat and add small components to these links as necessary.

  if any? other NI-nodes with [boat-ID = [boat-id] of fisherkid] [ ; new boat
   ask other NI-nodes with [boat-ID = [boat-id] of fisherkid] [
    if not link-neighbor? fisherkid [
     create-link-with fisherkid [
      set sibling? false
      set adjacent-increase? false]]
    if occ-type = 1 and not stay-at-home-dad? and not fisherman-caretaker? [ask link who fisherkid-who [set strength strength + Str-Boat-Same18]]
    if occ-type = 2 [ask link who fisherkid-who [set strength strength + Str-Boat-Same28]]
    if occ-type = 8 and age >= 10 [ask link who fisherkid-who [if not sibling? [set strength strength + Str-Boat-Same88]]]
    if fisherman-caretaker? [ask link who fisherkid-who [set strength strength + Str-Boat-Same8FC]]
   ]] ; closes ask other NI-nodes and if any? other

  ; If necessary, create links with fishers in adjacent boats
  if any? NI-nodes with [boat-ID + 1 = [boat-id] of fisherkid or boat-ID - 1 = [boat-id] of fisherkid][
   ask NI-nodes with [boat-ID + 1 = [boat-id] of fisherkid or boat-ID - 1 = [boat-id] of fisherkid][
    if not link-neighbor? fisherkid [
     create-link-with fisherkid [
      set sibling? false
      set adjacent-increase? false]]
   ] ; closes ask adjacent boat fishers
  ] ; closes if any? adjacent boat fishers

  ask my-links [if not sibling? [increase-adjacent]] ; Multiple children being adopted go through these methods sequentially. Since some of these children may still be assigned to the old boat, the sibling test prevents undesired increases between such pairs. Although the sibling? variable is not yet set true for links between a newly-adopted child and a child already living in the new household, no code is needed to prevent these links from increasing their strength. Newly adopted children are assigned to the new boat-id earlier in this check-boat method, and so they will not consider themselves in adjacent boats when proceeding through the increase-adjacent method.
 ]
end

to reassign-household-links [new-caretaker] ; called by all dependent children IF they are adopted into a NEW household to reflect their changed relationships with other individuals including the new caretaker. The specific values and variables that change are tied to daily activity schedules for different types of occupations and how often such pairs would come into contact with each other during these activities. Note that there might be surviving nodes (types 3, 4, or SDDH 8s, if the set of adopted children include at least one preschool-aged child) in their old dwelling that might also need to be adjusted accordingly.

 let adoptee self
```

```
  let adoptee-who who
  let adopted-household [household] of new-caretaker
  let adopted-dwelling [dwelling] of new-caretaker
  let old-household household
  let old-dwelling dwelling
  let adopted-church [church] of new-caretaker
  let new-church? false

  ; Children first check to see if they've been adopted into a household with a different church assignment
and thus if they need to "convert." They will reduce the strength of links with any former church members
and create links with all new church members set to the appropriate church strength.
  if church != adopted-church [set new-church? true]

  if new-church? [
    if any? NI-nodes with [link-neighbor? adoptee and church = [church] of adoptee][
      ask NI-nodes with [link-neighbor? adoptee and church = [church] of adoptee] [
        ifelse church = church1-id
          [ask link who adoptee-who [set strength strength - Str-Church1]]
          [ask link who adoptee-who [set strength strength - Str-Church2]]
      ] ]
    ask NI-nodes with [church = adopted-church][  ; Note that it is unnecessary to make sure the set
contains nodes, because there must be at least one node, the new caretaker, assigned to this church
      if not link-neighbor? adoptee [
        create-link-with adoptee [
          set sibling? false
          set adjacent-increase? false]]
      ifelse church = church1-id
        [ask link who adoptee-who [set strength strength + Str-Church1]]
        [ask link who adoptee-who [set strength strength + Str-Church2]]
    ]
    set church adopted-church] ; closes if new-church?

  ; Children then determine whether they were adopted into a different household within their previous
dwelling.

  ifelse adopted-dwelling = old-dwelling [
; if of ifelse dwelling...:

  ; Children then adjust the strengths of links by the difference between old and new households. These
values account for evening/night ticks and Sunday activities excluding church.
    ask NI-nodes with [link-neighbor? adoptee and household = adopted-household][
      ask link who adoptee-who [if not sibling? [set strength strength + (Str-DW-SameHH - Str-DW-DiffHH)]]]
    if any? NI-nodes with [link-neighbor? adoptee and household = old-household and age > 15][ ; Note:
this should include only 3s and 4s. All other members of the old-household will have either died
(otherwise they would have adopted the children) or are siblings also being adopted and thus are <= 15.
Because of this age test, the "if not sibling?" is unnecessary.
      ask NI-nodes with [link-neighbor? adoptee and household = old-household and age > 15][
        ask link who adoptee-who [set strength strength - (Str-DW-SameHH - Str-DW-DiffHH)]]]

  ; Children with occ-type 8 need not make any further changes. They move independently on Saturdays
and attend school all day on weekdays so their relationships with other SDSH and SDDH individuals are
equivalent or have negligible differences.
```

```
 ; Children with occ-type 9 increase the amount of time they spend with nodes in the new household. The
only possible survivors in the old household are individuals of occ-types 3 and 4 who are not allowed to
adopt preschool-aged children. Both of these occ-types move independently of other members in their
household, so no changes are needed for those links.

  if occ-type = 9 [
   ask NI-nodes with [link-neighbor? adoptee and household = adopted-household][
    if occ-type = 7 [ask link who adoptee-who [set strength strength + (Str-Both-Home79-SameHH - Str-
Both-Home79-DiffHH) + (Sat-79-SameHH - Sat-79-DiffHH)]]
    if occ-type = 9 [ask link who adoptee-who [set strength strength + (Str-Both-Home99-SameHH - Str-
Both-Home99-DiffHH) + (Sat-99-SameHH - Sat-99-DiffHH)]]
    if stay-at-home-dad? [ask link who adoptee-who [set strength strength + (Str-Both-Home9SAHD-
SameHH - Str-Both-Home9SAHD-DiffHH) + (Sat-9SAHD-SameHH - Sat-9SAHD-DiffHH)]]
   ] ; closes NI-nodes in new/adopted hh
  ] ; closes if occ-type = 9
 ] ; closes if of ifelse dwelling...

; else of ifelse dwelling..., i.e. adopted into a different dwelling
  ; First, the children need to create a link if they were adopted into a previously-unlinked dwelling. Links
with members of the new household are created in the reassign-adopted-links method, so this is really
only for NI-nodes in a different household within the same new dwelling.
  [ask NI-nodes with [dwelling = adopted-dwelling] [
   if not link-neighbor? adoptee [
    create-link-with adoptee [
     set sibling? false
     set adjacent-increase? false]]]

  ; Children increase link strength with all members of the new dwelling by the appropriate evening/non-
church Sunday values, and decrease links with any survivors in their previous dwelling. This might include
surviving 3s or 4s, or school-aged children in other households (cared for by teacher-caretakers). If there
were any other adults in the same dwelling, the children would have been adopted by one of those
adults.
  ask NI-nodes with [link-neighbor? adoptee and dwelling = adopted-dwelling][
   ifelse household = adopted-household
    [ask link who adoptee-who [if not sibling? [set strength strength + Str-DW-SameHH]]]
    [ask link who adoptee-who [if not sibling? [set strength strength + Str-DW-DiffHH]]]
  ]
  if any? NI-nodes with [link-neighbor? adoptee and dwelling = old-dwelling][
   ask NI-nodes with [link-neighbor? adoptee and dwelling = old-dwelling] [
    ifelse household = old-household
     [ask link who adoptee-who [if not sibling? [set strength strength - Str-DW-SameHH]]]
     [ask link who adoptee-who [if not sibling? [set strength strength - Str-DW-DiffHH]]]
   ] ]

  ; Younger school-aged children adjust their values for strength components related to Saturday
activities.
  if occ-type = 8 and age < 10 [
   ask NI-nodes with [link-neighbor? myself and dwelling = adopted-dwelling][
    if occ-type = 0 [ask link who adoptee-who [set strength strength + Sat-08y]]
    if occ-type = 2 [ask link who adoptee-who [set strength strength + Sat-28y]]
    if occ-type = 3 and not teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-
38y]]
    if occ-type = 7 [ask link who adoptee-who [set strength strength + Sat-78y]]
```

```
    if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8y8y]]]
    if occ-type = 8 and age >= 10 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8y8o]]]
    if occ-type = 9 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8y9]]]
    if stay-at-home-dad? [ask link who adoptee-who [set strength strength + Sat-8ySAHD]]
    if teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-8yTC]]
    ] ; closes ask link-neighbors adopted dwelling
   if any? NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
    ask NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
     if occ-type = 3 and not teacher-caretaker? [ask link who adoptee-who [set strength strength - Sat-38y]] ; There may be surviving 3s in either household who cannot adopt because there are preschool-aged children. This line thus needs to account for both SDSH and SDDH teachers/resident clergy. No changes are necessary for links with surviving traveling clergy.
     if household != old-household [
      ; If there were any surviving adults (except for teachers/clergy or teacher-caretakers) in either household, the children would be adopted by them. Therefore, there is no need to check for any other types of adults. However, if the children being adopted in this method include preschool-aged children and the other household in the same dwelling includes only older children cared for by a teacher-caretaker, then all siblings would be moved to a different dwelling since the teacher-caretaker would not be allowed to adopt preschool-aged children. The following statements thus adjust the strengths of links between the adopted children and any older children remaining in the old household.
      if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength - Sat-8y8y]]]
      if occ-type = 8 and age >= 10 [ask link who adoptee-who [if not sibling? [set strength strength - Sat-8y8o]]]
      if teacher-caretaker? [ask link who [who] of myself [set strength strength - Sat-8yTC]]
      ] ; closes if household !=...
   ]]; closes ask link-neighbors with old dwelling and if any?
  ] ; closes young occ-type 8

  ; Older school-aged children adjust their values for strength components related to Saturday activities.
  if occ-type = 8 and age >= 10 [
   ask NI-nodes with [link-neighbor? myself and dwelling = adopted-dwelling][
    if occ-type = 0 [ask link who adoptee-who [set strength strength + Sat-08o]]
    if occ-type = 2 [ask link who adoptee-who [set strength strength + Sat-28o]]
    if occ-type = 3 and not teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-38o]]
    if occ-type = 7 [ask link who adoptee-who [set strength strength + Sat-78o]]
    if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8y8o]]]
    ; Older schoolchildren (8s >= 10) are not included here because the strength adjustment is too small to make a meaningful difference
    if occ-type = 9 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8o9]]]
    if stay-at-home-dad? [ask link who adoptee-who [set strength strength + Sat-8oSAHD]]
    if teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-8oTC]]
    ] ; closes ask link-neighbors adopted dwelling
   if any? NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
    ask NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
     if occ-type = 3 and not teacher-caretaker? [ask link who [who] of myself [set strength strength - Sat-38o]]
     if household != old-household [
```

```
      if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength - Sat-8y8o]]]
      if teacher-caretaker? [ask link who adoptee-who [set strength strength - Sat-8oTC]]
      ] ; closes if household !=...
     ]]; closes ask link-neighbors with old dwelling and if any?
   ] ; closes old occ-type 8

  ; Preschool-aged children adjust their values for strength components related to staying home M-F and Saturday activities.
  if occ-type = 9 [  ; No age test is needed because the turtle-set calling this method will never include nodes > 15 years old with occ-type 9
   ask NI-nodes with [link-neighbor? myself and dwelling = adopted-dwelling][
    if occ-type = 2 [ask link who adoptee-who [set strength strength + Str-Both-Home29 + Sat-29]]
    if occ-type = 3 and not teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-39]]
    if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8y9]]]
    if occ-type = 8 and age >= 10 [ask link who adoptee-who [if not sibling? [set strength strength + Sat-8o9]]]
    ifelse household = adopted-household
     [if occ-type = 7 [ask link who adoptee-who [set strength strength + Str-Both-Home79-SameHH + Sat-79-SameHH]]
      if occ-type = 9 [ask link who adoptee-who [if not sibling? [set strength strength + Str-Both-Home99-SameHH + Sat-99-SameHH]]]
      if stay-at-home-dad? [ask link who adoptee-who [set strength strength + Str-Both-Home9SAHD-SameHH + Sat-9SAHD-SameHH]]
      ] ; closes if of ifelse household...
     [if occ-type = 0 [ask link who adoptee-who [set strength strength + Str-Both-Home09 + Sat-09-DiffHH]]
      if occ-type = 7 [ask link who adoptee-who [set strength strength + Str-Both-Home79-DiffHH + Sat-79-DiffHH]]
      if occ-type = 9 [ask link who adoptee-who [if not sibling? [set strength strength + Str-Both-Home99-DiffHH + Sat-99-DiffHH]]]
      if stay-at-home-dad? [ask link who adoptee-who [set strength strength + Str-Both-Home9SAHD-DiffHH + Sat-9SAHD-DiffHH]]
      if teacher-caretaker? [ask link who adoptee-who [set strength strength + Sat-9TC]]
      ] ; closes else of ifelse household
     ] ; closes ask link-neighbors adopted dwelling
   if any? NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
    ask NI-nodes with [link-neighbor? myself and dwelling = old-dwelling][
     if occ-type = 3 and not teacher-caretaker? [ask link who adoptee-who [set strength strength - Sat-39]]
     if household != old-household [
      if occ-type = 8 and age < 10 [ask link who adoptee-who [if not sibling? [set strength strength - Sat-8y9]]]
      if occ-type = 8 and age >= 10 [ask link who adoptee-who [if not sibling? [set strength strength - Sat-8o9]]]
      if teacher-caretaker? [ask link who adoptee-who [set strength strength - Sat-9TC]]
      ] ; closes else of ifelse household..
    ]]; closes ask link-neighbors with old dwelling and if any?
   ] ; closes occ-type 9
 ] ; closes else of ifelse dwelling...
```

```
    ; All children will conclude by resetting their household and dwelling variables.
    set household [household] of new-caretaker
    set dwelling [dwelling] of new-caretaker
end

to restore-fishing-links ; called by a stay-at-home-dad caretaker who is returning to fishing after all dependent (preschool-aged) children have died. It is essentially the reverse of the process he went through when he became caretaker - he needs to increase link strength by the appropriate fishing components and reduce them by the appropriate components for staying home or Saturday activities.

  let dad-dwelling dwelling
  let dad-household household
  let dad-node self
  let dad-who who
  let dad-boat boat-ID

  ; The first block of code is to re-form any links with fishers on the same boat that might have been removed (strength went to 0 and the link died) when the SAHD gave up fishing.

  if any? other NI-nodes with [(occ-type = 0 or occ-type = 1 or occ-type = 2 or (occ-type = 8 and age >= 10)) and boat-id = dad-boat and not link-neighbor? dad-node] [
    ask other NI-nodes with [(occ-type = 0 or occ-type = 1 or occ-type = 2 or (occ-type = 8 and age >= 10)) and boat-id = dad-boat and not link-neighbor? dad-node] [
      create-link-with dad-node [
        set sibling? false
        set adjacent-increase? false]]]

  if any? NI-nodes with [link-neighbor? dad-node and dwelling = dad-dwelling][
    ask NI-nodes with [link-neighbor? dad-node and dwelling = dad-dwelling][
      if occ-type = 0 and household != dad-household [ask link who dad-who [set strength strength - Str-Both-Home0SAHD - Sat-0SAHD]]
      if occ-type = 2 [ask link who dad-who [set strength strength - Str-Both-Home2SAHD - Sat-2SAHD]]
      if occ-type = 3 and not teacher-caretaker? [ask link who dad-who [set strength strength - Sat-3SAHD]]
      if occ-type = 7 and household != dad-household [ask link who dad-who [set strength strength - Str-Both-Home7SAHD - Sat-7SAHD]]
      if occ-type = 8 and age < 10 [ask link who dad-who [set strength strength - Sat-8ySAHD]]
      if occ-type = 8 and age >= 10 [ask link who dad-who [set strength strength - Sat-8oSAHD]]
      if occ-type = 9 and household != dad-household [ask link who dad-who [set strength strength - Str-Both-Home9SAHD-DiffHH - Sat-9SAHD-DiffHH]] ; This part of the method differs slightly from the expected reverse of the reassign-caretaker-links method because there would be no surviving 9s in the same household if a SAHD is allowed to return to fishing.
      if stay-at-home-dad? and household != dad-household [ask link who dad-who [set strength strength - Str-Both-HomeSAHDx2 - Sat-SAHDx2]]
      if teacher-caretaker? and household != dad-household [ask link who dad-who [set strength strength - Sat-TCSAHD]]
      ] ; closes ask NI-nodes
    ] ; closes if any?
  if any? NI-nodes with [link-neighbor? dad-node and boat-ID = dad-boat][
    ask NI-nodes with [link-neighbor? dad-node and boat-ID = dad-boat][
      if occ-type = 0 and household != dad-household [ask link who dad-who [set strength strength + Str-Boat-Same01]]
      if occ-type = 1 and not fisherman-caretaker? and not stay-at-home-dad? [ask link who dad-who [set strength strength + Str-Boat-Same11]]
```

```
      if occ-type = 2 [ask link who dad-who [set strength strength + Str-Boat-Same12]]
      if occ-type = 8 and age >= 10 [ask link who dad-who [set strength strength + Str-Boat-Same18]]
      if fisherman-caretaker? and household != dad-household [ask link who dad-who [set strength strength
+ Str-Boat-Same1FC]]
      ] ; closes ask NI-nodes
    ] ; closes if any?

  ; If necessary, the fisherman needs to form links with fishers assigned to adjacent boats. He then calls the
increase-adjacent procedure to add the appropriate small strength components to these links.
  if any? NI-nodes with [boat-ID + 1 = [boat-id] of dad-node or boat-ID - 1 = [boat-id] of dad-node][
    ask NI-nodes with [boat-ID + 1 = [boat-id] of dad-node or boat-ID - 1 = [boat-id] of dad-node][
      if not link-neighbor? dad-node [create-link-with dad-node [
        set sibling? false
        set adjacent-increase? false]]
    ]] ; closes ask any? and if any

  ask my-links [increase-adjacent]
end

to increase-adjacent
    ; This procedure adds a small amount of strength to each link between fishers in adjacent boats to
account for interaction among crews. In the ABM, all fishers have a chance of selecting cells along the
border between adjacent boats, but the probability changes according to how frequently the agent fishes
which is determined by its occ-type. The value added here for each potential pair of fishers is determined
by taking the proportion of ticks per week both nodes choose to fish multiplied by a scaling factor that
takes into account the size of boats and the borders between boats. See the Info tab for more information
on how scaling factors are calculated.

    ; This method is called by all links, or my-links of particular nodes, three times during the course of a
simulation: 1) during initialization/setup, 2) when occ-type 8 kids >= 10 are adopted into households that
are associated with new/different boats, and 3) when stay-at-home-dads (occ-type 1) return to fishing
upon the death of all preschool children under their care. These latter two situations are the only times
that fishers need to worry about new or different nodes fishing in adjacent boats. While other nodes
might change the amount of time they fish because of adoption-related adjustments, these changes only
happen once (i.e. they never return to previous fishing amounts like SAHDs) and they never change boats
like children. Further explanations for specific situations can be found in reassign-caretaker-links.

  if not adjacent-increase? [ ; During initialization, all links set this variable to false, so they will all
complete this procedure. During simulations, the variable is also set to false if a node stops fishing entirely
for caretaking responsibilities or if children switch to another boat while fishers remain assigned to crews
adjacent to the old boat. Therefore, this test prevents additional increases to links that already have
adjacent-crew interactions accounted for.

    ask one-of both-ends [
      if boat-id + 1 = [boat-id] of other-end or boat-id - 1 = [boat-id] of other-end [

        if occ-type = 0 [
          if [occ-type] of other-end = 0 [ask link-with other-end [
              set strength strength + Str-Boat-Adj00
              set adjacent-increase? true]]
          if [occ-type] of other-end = 1 and not [stay-at-home-dad?] of other-end [ask link-with other-end [
              set strength strength + Str-Boat-Adj01
              set adjacent-increase? true]]
```

```
        if [occ-type] of other-end = 2 [ask link-with other-end [
           set strength strength + Str-Boat-Adj02
           set adjacent-increase? true]]
        ; Occ-types 0 and 8 never fish at the same time, so no adjacent boat increase is possible
      ] ; closes occ-type 0

      if occ-type = 1 and not stay-at-home-dad? [
        if [occ-type] of other-end = 0 [ask link-with other-end [
           set strength strength + Str-Boat-Adj01
           set adjacent-increase? true]]
        if [occ-type] of other-end = 1 and not [stay-at-home-dad?] of other-end [ask link-with other-end [
           set strength strength + Str-Boat-Adj11
           set adjacent-increase? true]]
        if [occ-type] of other-end = 2 [ask link-with other-end [
           set strength strength + Str-Boat-Adj12
           set adjacent-increase? true]]
        if [occ-type] of other-end = 8 and [age] of other-end >= 10 [ask link-with other-end [
           set strength strength + Str-Boat-Adj18
           set adjacent-increase? true]]
      ] ; closes occ-type 1

      if occ-type = 2 [
        if [occ-type] of other-end = 0 [ask link-with other-end [
           set strength strength + Str-Boat-Adj02
           set adjacent-increase? true]]
        if [occ-type] of other-end = 1 and not [stay-at-home-dad?] of other-end [ask link-with other-end [
           set strength strength + Str-Boat-Adj12
           set adjacent-increase? true]]
        if [occ-type] of other-end = 2 [ask link-with other-end [
           set strength strength + Str-Boat-Adj22
           set adjacent-increase? true]]
        if [occ-type] of other-end = 8 and [age] of other-end >= 10 [ask link-with other-end [
           set strength strength + Str-Boat-Adj28
           set adjacent-increase? true]]
      ] ; closes occ-type 2

      if occ-type = 8 and age >= 10 [
        ; Occ-types 0 and 8 never fish at the same time, so no adjacent boat increase is possible
        if [occ-type] of other-end = 1 and not [stay-at-home-dad?] of other-end [ask link-with other-end [
           set strength strength + Str-Boat-Adj18
           set adjacent-increase? true]]
        if [occ-type] of other-end = 2 [ask link-with other-end [
           set strength strength + Str-Boat-Adj28
           set adjacent-increase? true]]
        if [occ-type] of other-end = 8 and [age] of other-end >= 10 [ask link-with other-end [
           set strength strength + Str-Boat-Adj88
           set adjacent-increase? true]]
      ] ; closes occ-type 8
     ] ; closes adjacent boat
   ] ; closes one-of both-ends
  ] ; if not adjacent-increase?
end
```

```
;;Data Collection and Display Update Methods

to color-links  ; Called by links
  set color scale-color sky strength 0.3 0 ;sets the color of the links scaling them according to their
strength, with darker colors indicating stronger weights. 0.3 is chosen as the max value because the
strongest links possible in the model are given a value of (.22 + Str-Church). A slightly higher value allows
for stochastic variation that might occur with affinity increases or changes during adoption processes,
while still allowing for a visually distinctive range of colors in the scale.
end

to update-daily-output
  tally
  draw-plots
  write-to-daily-file
end

to tally
  set num-susceptible count NI-nodes with [disease-status = 0]
  set num-exposed count NI-nodes with [disease-status = 1]
  set num-infectious count NI-nodes with [disease-status = 2]
  set num-recovered count NI-nodes with [disease-status = 3]
  set num-dead count ghosts
  set RD num-recovered + num-dead ; size of epidemic excluding orphans who have left the community
  set RDNsO RD + num-infected-orphans-gone ; size of epidemic including orphans who have left the
community
  set SRDO num-susceptible + RD + num-orphans-gone ; should equal pop-size if the epidemic concluded
by the time the simulation ended
end

to draw-plots
  set-current-plot "Epidemic Curve"
  set-current-plot-pen "Susceptible Nodes"
  plot num-susceptible
  set-current-plot-pen "Exposed Nodes"
  plot num-exposed
  set-current-plot-pen "Infectious Nodes"
  plot num-infectious
  set-current-plot-pen "Recovered Nodes"
  plot num-recovered
  set-current-plot-pen "Dead Nodes"
  plot num-dead
end

to write-to-daily-file
  file-open "DailyData.csv"
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ") ; Unlike the ABM, the Netlogo model clock starts at tick 0. One tick is
added in data recording to ensure consistency with the ABM model. For example, the first tick the first
case is infectious is latent period + 1, i.e. tick 7 if the latent period is 6 days. This also ensures that the data
recording is consistent with the visualization.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
  file-type (word death-prob ", ")
```

```
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
  file-type (word first-case-occ ", ")
  file-type (word num-susceptible ", ")
  file-type (word count NI-nodes with [newly-infected?] ", ")
  file-type (word num-exposed ", ")
  file-type (word num-infectious ", ")
  file-type (word num-recovered ", ")
  file-type (word count ghosts with [newly-dead?] ", ")
  file-type (word num-dead ", ")
  file-type (word num-infected-orphans-gone ", ")
  file-print (word num-orphans-gone ", ")
  file-close
end

to update-final-output
  write-to-cases-file
  write-to-final-file
end

to write-to-cases-file
  file-open "CasesData.csv"
  foreach sort-on [node-id] turtles[  ; This code forces the nodes to print the following information in order
(sorted by node-id)
    ask ? [
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ") ; See comment above in the write-to-daily-file method.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
  file-type (word death-prob ", ")
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
  file-type (word first-case-occ ", ")
  file-type (word node-id ", ")
  file-type (word dwelling ", ")
  file-type (word occupation ", ")
  file-type (word infector-id ", ")
  file-type (word infector-dwelling ", ")
  file-type (word infector-occ ", ")
  file-type (word time-infected ", ")
  file-type (word time-died ", ")
  file-print (word time-leaves-village ", ")]]
  file-close
end

to write-to-final-file
  file-open "FinalData.csv"
  file-type (word behaviorspace-run-number ", ")
  file-type (word (ticks + 1) ", ") ; See comment above in the write-to-daily-file method.
  file-type (word pop-size ", ")
  file-type (word transmission-prob ", ")
```

```
  file-type (word death-prob ", ")
  file-type (word latent-period ", ")
  file-type (word infectious-period ", ")
  file-type (word first-case ", ")
  file-type (word first-case-occ ", ")
  file-type (word num-susceptible ", ")
  file-type (word num-recovered ", ")
  file-type (word num-dead ", ")
  file-type (word num-infected-orphans-gone ", ")
  file-type (word num-orphans-gone ", ")
  file-type (word RD ", ")
  file-type (word RDNsO ", ")
  file-print (word SRDO ", ")
  file-close
end

;;Reporter Methods

;; Procedure for looking up a node's id.
to-report get-node [id]
  report one-of turtles with [node-id = id]
end
```

APPENDIX C – STRENGTH CALCULATIONS FOR OCCUPATION PAIRS IN THE NETWORK MODEL

The following tables present the formulas used to calculate the strengths of links between individuals assigned to different occupation types in the social network model. To conserve space, the tables include only the occupation pairs for which the final columns in each table are meaningful. For example, individuals who only attend the same church and do not interact the rest of the week, or who do not interact at all, are not included. Pairs who are assigned to the same dwelling but only have a chance of interacting during evening ticks are excluded from Tables C.1-C.6 but are included in Tables C.7-C.12.

In all tables, the first column ("Occ Pair") lists the occupation codes or categories for the two individuals involved. For example, 01 refers to the interactions between a 0 node and a 1 node. Individuals in occupation code 8 behave differently on Saturdays based on age, so 8y represents the younger schoolchildren (< 10 years) and 8o represents older schoolchildren (10-15 years). Males who are primary caretakers of children are designated by abbreviations for fisherman-caretakers (FC), teacher-caretakers (TC) and stay-at-home-dads (SAHD).

Tables C.1-C.6 present the formulas for pairs of nodes assigned to different dwelling, household and boat combinations. In individual cells, the coefficients are the number of ticks the two agents engage in the relevant behavior, determined by multiplying the probability each agent will choose that behavior during that time step. The abbreviations associated with each coefficient refer to the type of behavior or location where the behavior occurs. F refers to fishing, or interactions in boats. S refers to the school. SH refers to Stay Home, which means the individuals remain in their assigned dwellings (or travel as a group to another dwelling), while SA is the equivalent of this behavior on Saturdays. Cells with an entry of “XX” designate time periods where the two individuals are not in the same building. The various coefficients are added and reported in the final column, which is also column 2 in Tables C.7-C.12.

This second set of tables demonstrates how the coefficient formulas are converted into link strengths. For pairs assigned to the same dwelling, the evening and Sunday strengths are first added to the overall formula; Sunday values exclude church interactions, which are added to links upon initialization of the network model. The total number of ticks spent in different building types are determined and divided by 42, i.e. the total possible number of ticks in the modeled week. These proportions are multiplied by the building-specific scaling factors, as described in the Methods chapter. The resulting products are added and then rounded to the nearest thousandth to give the overall strength for the corresponding pair of nodes.

Table C.1. Calculation of strength formulas for individuals assigned to the same dwelling, same household and same boat

Occ Pair[a]	MF 6a10a	MF 10a2p	MF 2p6p	Weekday Sum * 5	Sat 6a10a	Sat 10a2p	Sat 2p6p	Sat Sum	Strength Formula (column 2, table 7)
01	XX	.8F	.8F	8F	XX	XX	XX	XX	8F
02	1SH	.64F +.0256SH	.64F +.04SH	6.4F +5.328SH	1SA	.08SA	.2SA	1.28SA	6.4F + 5.328SH + 1.28SA
03	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
08y	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
08o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
11	1F	1F	1F	15F	1F	1F	1F	3F	18F
12	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
18o	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
1FC	1F	1F	1F	15F	1F	1F	1F	3F	18F
22	1SH	.64F +.0256SH	.64F +.04SH	6.4F +5.328SH	1SA	.64F +.0256SA	.64F +.04SA	1.28F +1.0656SA	7.68F + 5.328SH + 1.0656SA
23	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
27	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
28y	XX	XX	XX	XX	1SA	.016SA	.2SA	1.216SA	1.216SA
28o	XX	XX	XX	XX	.2SA	.64F +.0064SA	.64F +.04SA	1.28F +.2464SA	1.28F + .2464SA
29	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
2SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.16SA	.2SA	1.36SA	6.8SH + 1.36SA
2FC	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
2TC	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
33	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
37	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
38y	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
38o	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA

39	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
3SAHD	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
3TC	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
78y	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
78o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
79	1SH	1SH	1SH	15SH	1SH	1SH	1SH	3SA	15SH + 3SA
8y8y	1S	1S	1S	15S	1SA	.64S +.04SA	1SA	.64S +2.04SA	15S + .64S + 2.04SA
8y8o	1S	1S	1S	15S	.2SA	.128S +.004SA	.2SA	.128S +.404SA	15S + .128S + .404SA
8y9	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
8ySAHD	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
8yTC	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
8o8o	1S	1S	1S	15S	.64F +.04SA	.64F +.0256S +.0016SA	.64F +.04SA	1.92F +.0256S +.0816SA	15S + 1.92F + .0256S + .0816SA
8o9	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
8oSAHD	XX	XX	XX	XX	.2SA	.04SA	.2SA	.44SA	.44SA
8oFC	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
8oTC	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
99	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA
9SAHD	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA

Table C.2. Calculation of strength formulas for individuals assigned to the same dwelling, different household and same boat

Occ Pair	MF 6a10a	MF 10a2p	MF 2p6p	Weekday Sum * 5	Sat 6a10a	Sat 10a2p	Sat 2p6p	Sat Sum	Strength Formula (column 2, table 8)
00	1SH	.64F +.0256SH	.64F +.04SH	6.4F +5.328SH	1SA	.25SA	1SA	2.25SA	6.4F + 5.328SH +2.25SA
01	XX	.8F	.8F	8F	XX	XX	XX	XX	8F
02	1SH	.64F +.0256SH	.64F +.04SH	6.4F +5.328SH	1SA	.08SA	.2SA	1.28SA	6.4F + 5.328SH + 1.28SA
03	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
07	1SH	.08SH	.2SH	6.4SH	1SA	.25SA	1SA	2.25SA	6.4SH + 2.25SA
08y	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
08o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
09	1SH	.08SH	.2SH	6.4SH	1SA	.25SA	1SA	2.25SA	6.4SH + 2.25SA
0SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.5SA	1SA	2.5SA	6.8SH + 2.5SA
0FC	XX	.8F	.8F	8F	XX	XX	XX	XX	8F
0TC	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
11	1F	1F	1F	15F	1F	1F	1F	3F	18F
12	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
18o	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
1FC	1F	1F	1F	15F	1F	1F	1F	3F	18F
22	1SH	.64F +.0256SH	.64F +.04SH	6.4F +5.328SH	1SA	.64F +.0256SA	.64F +.04SA	1.28F +1.0656SA	7.68F + 5.328SH + 1.0656SA
23	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
27	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
28y	XX	XX	XX	XX	1SA	.016SA	.2SA	1.216SA	1.216SA
28o	XX	XX	XX	XX	.2SA	.64F +.0064SA	.64F +.04SA	1.28F +.2464SA	1.28F + .2464SA
29	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA

2SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.16SA	.2SA	1.36SA	6.8SH + 1.36SA
2FC	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
2TC	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
33	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
37	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
38y	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
38o	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
39	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
3SAHD	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
3TC	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
77	1SH	.25SH	1SH	11.25SH	1SA	.25SA	1SA	2.25SA	11.25SH + 2.25SA
78y	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
78o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
79	1SH	.25SH	1SH	11.25SH	1SA	.25SA	1SA	2.25SA	11.25SH + 2.25SA
7SAHD	1SH	.5SH	1SH	12.5SH	1SA	.5SA	1SA	2.5SA	12.5SH + 2.5SA
7TC	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
8y8y	1S	1S	1S	15S	1SA	.64S +.01SA	1SA	.64S +2.01SA	15.64S + 2.01SA
8y8o	1S	1S	1S	15S	.2SA	.128S +.004SA	.2SA	.128S +.404SA	15.128S + .404SA
8y9	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
8ySAHD	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
8yTC	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
8o8o	1S	1S	1S	15S	.64F +.04SA	.64F +.0256S +.0016SA	.64F +.04SA	1.92F +.0816SA +.0256S	15.0256S + 1.92F + .0816SA
8o9	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
8oSAHD	XX	XX	XX	XX	.2SA	.04SA	.2SA	.44SA	.44SA

8oFC	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
8oTC	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
99	1SH	.25SH	1SH	11.25SH	1SH	.25SH	1SH	2.25SA	11.25SH + 2.25SA
9SAHD	1SH	.5SH	1SH	12.5SH	1SA	.5SA	1SA	2.5SA	12.5SH + 2.5SA
9TC	XX	XX	XX	XX	1SA	.25S	1SA	2.25SA	2.25SA
SAHDx2	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA
SAHDTC	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
FCx2	1F	1F	1F	15F	1F	1F	1F	3F	18F
TCx2	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA

Table C.3. Calculation of strength formulas for individuals assigned to different dwellings but the same boat

Occ Pair	**MF 6a10a**	**MF 10a2p**	**MF 2p6p**	**Weekday Sum * 5**	**Sat 6a10a**	**Sat 10a2p**	**Sat 2p6p**	**Sat Sum**	***Strength Formula (column 2, table 9)***
00	XX	.64F	.64F	6.4F	XX	XX	XX	XX	6.4F
01	XX	.8F	.8F	8F	XX	XX	XX	XX	8F
02	XX	.64F	.64F	6.4F	XX	XX	XX	XX	6.4F
0FC	XX	.8F	.8F	8F	XX	XX	XX	XX	8F
11	1F	1F	1F	15F	1F	1F	1F	3F	18F
12	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
18o	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
1FC	1F	1F	1F	15F	1F	1F	1F	3F	18F
22	XX	.64F	.64F	6.4F	XX	.64F	.64F	1.28F	7.68F
28o	XX	XX	XX	XX	XX	.64F	.64F	1.28F	1.28F
2FC	XX	.8F	.8F	8F	XX	.8F	.8F	1.6F	9.6F
33	1S	1S	1S	15S	XX	XX	XX	XX	15S
38y	1S	1S	1S	15S	XX	XX	XX	XX	15S
38o	1S	1S	1S	15S	XX	XX	XX	XX	15S
3TC	1S	1S	1S	15S	XX	XX	XX	XX	15S
8y8y	1S	1S	1S	15S	XX	.64S	XX	.64S	15.64S
8y8o	1S	1S	1S	15S	XX	.128S	XX	.128S	15.128S
8yTC	1S	1S	1S	15S	XX	XX	XX	XX	15S
8o8o	1S	1S	1S	15S	.64F	.64F +.0256S	.64F	1.92F +.0256S	15.0256S + 1.92F
8oFC	XX	XX	XX	XX	.8F	.8F	.8F	2.4F	2.4F
8oTC	1S	1S	1S	15S	XX	XX	XX	XX	15S
FCx2	1F	1F	1F	15F	1F	1F	1F	3F	18F
TCx2	1S	1S	1S	15S	XX	XX	XX	XX	15S

Table C.4. Calculation of strength formulas for individuals assigned to the same dwelling and household but a different boat

Occ Pair	**MF 6a10a**	**MF 10a2p**	**MF 2p6p**	**Weekday Sum * 5**	**Sat 6a10a**	**Sat 10a2p**	**Sat 2p6p**	**Sat Sum**	***Strength Formula (column 2, table 10)***
02	1SH	.0256SH	.04SH	5.328SH	1SA	.08SA	.2SA	1.28SA	5.328SH + 1.28SA
03	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
08y	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
08o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
22	1SH	.0256SH	.04SH	5.328SH	1SA	.0256SA	.04SA	1.0656SA	5.328SH + 1.0656SA
23	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
27	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
28y	XX	XX	XX	XX	1SA	.016SA	.2SA	1.216SA	1.216SA
28o	XX	XX	XX	XX	.2SA	.0064SA	.04SA	.2464SA	.2464SA
29	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
2SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.16SA	.2SA	1.36SA	6.8SH + 1.36SA
2TC	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
33	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
37	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
38y	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
38o	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S +.42SA
39	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
3SAHD	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
3TC	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
78y	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
78o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
79	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA
8y8y	1S	1S	1S	15S	1SA	.64S +.04SA	1SA	.64S +2.04SA	15.64S + 2.04SA

8y8o	1S	1S	1S	15S	.2SA	.128S + .004SA	.2SA	.128S +.404SA	15.128S + .404SA
8y9	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
8ySAHD	XX	XX	XX	XX	1SA	.2SA	1SA	2.2SA	2.2SA
8yTC	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
8o8o	1S	1S	1S	15S	.04SA	.0256S +.0016SA	.04SA	.0256S +.0816SA	15.0256S + .0816SA
8o9	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
8oSAHD	XX	XX	XX	XX	.2SA	.04SA	.2A	.44SA	.44SA
8oTC	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
99	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA
9SAHD	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA

Table C.5. Calculation of strength formulas for individuals assigned to the same dwelling, different household and different boat

Occ Pair	**MF 6a10a**	**MF 10a2p**	**MF 2p6p**	**Weekday Sum * 5**	**Sat 6a10a**	**Sat 10a2p**	**Sat 2p6p**	**Sat Sum**	***Strength Formula (column 2, table 11)***
00	1SH	.0256SH	.04SH	5.328SH	1SA	.25SA	1SA	2.25SA	5.328SH + 2.25SA
02	1SH	.0256SH	.04SH	5.328SH	1SA	.08SA	.2SA	1.28SA	5.328SH + 1.28SA
03	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
07	1SH	.08SH	.2SH	6.4SH	1SA	.25SA	1SA	2.25SA	6.4SH + 2.25SA
08y	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
08o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
09	1SH	.08SH	.2SH	6.4SH	1SA	.25SA	1SA	2.25SA	6.4SH + 2.25SA
0SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.5SA	1SA	2.5SA	6.8SH + 2.5SA
0TC	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
22	1SH	.0256SH	.04SH	5.328SH	1SA	.0256SA	.04SA	1.0656SA	5.328SH + 1.0656SA
23	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
27	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
28y	XX	XX	XX	XX	1SA	.016SA	.2SA	1.216SA	1.216SA
28o	XX	XX	XX	XX	.2SA	.0064SA	.04SA	.2464SA	.2464SA
29	1SH	.08SH	.2SH	6.4SH	1SA	.08SA	.2SA	1.28SA	6.4SH + 1.28SA
2SAHD	1SH	.16SH	.2SH	6.8SH	1SA	.16SA	.2SA	1.36SA	6.8SH + 1.36SA
2TC	XX	XX	XX	XX	1SA	.08SA	.2SA	1.28SA	1.28SA
33	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA
37	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
38y	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
38o	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
39	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
3SAHD	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
3TC	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA

77	1SH	.25SH	1SH	11.25SH	1SA	.25SA	1SA	2.25SA	11.25SH + 2.25SA
78y	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
78o	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
79	1SH	.25SH	1SH	11.25SH	1SA	.25SA	1SA	2.25SA	11.25SH + 2.25SA
7SAHD	1SH	.5SH	1SH	12.5SH	1SA	.5SA	1SA	2.5SA	12.5SH + 2.5SA
7TC	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
8y8y	1S	1S	1S	15S	1SA	.64S +.01SA	1SA	.64S +2.01SA	15.64S + 2.01SA
8y8o	1S	1S	1S	15S	.2SA	.128S +.004SA	.2SA	.128S +.404SA	15.128S + .404SA
8y9	XX	XX	XX	XX	1SA	.05SA	1SA	2.05SA	2.05SA
8ySAHD	XX	XX	XX	XX	1SA	.1SA	1SA	2.1SA	2.1SA
8yTC	1S	1S	1S	15S	1SA	.05SA	1SA	2.05SA	15S + 2.05SA
8o8o	1S	1S	1S	15S	.04SA	.0256SA +.0016SA	.04SA	.0256S +.0816SA	15.0256S + .0816SA
8o9	XX	XX	XX	XX	.2SA	.02SA	.2SA	.42SA	.42SA
8oSAHD	XX	XX	XX	XX	.2SA	.04SA	.2SA	.44SA	.44SA
8oTC	1S	1S	1S	15S	.2SA	.02SA	.2SA	.42SA	15S + .42SA
99	1SH	.25SH	1SH	11.25SH	1SA	.25SA	1SA	2.25SA	11.25SH + 2.25SA
9SAHD	1SH	.5SH	1SH	12.5SH	1SA	.5SA	1SA	2.5SA	12.5SH + 2.5SA
9TC	XX	XX	XX	XX	1SA	.25SA	1SA	2.25SA	2.25SA
SAHDx2	1SH	1SH	1SH	15SH	1SA	1SA	1SA	3SA	15SH + 3SA
SAHDTC	XX	XX	XX	XX	1SA	.5SA	1SA	2.5SA	2.5SA
TCx2	1S	1S	1S	15S	1SA	.25SA	1SA	2.25SA	15S + 2.25SA

Table C.6. Calculation of strength formulas for individuals assigned to different dwellings and different boats

Occ Pair	MF 6a10a	MF 10a2p	MF 2p6p	Weekday Sum * 5	Sat 6a10a	Sat 10a2p	Sat 2p6p	Sat Sum	***Strength Formula (column 2, table 12)***
33	1S	1S	1S	15S	XX	XX	XX	XX	15S
38y	1S	1S	1S	15S	XX	XX	XX	XX	15S
38o	1S	1S	1S	15S	XX	XX	XX	XX	15S
3TC	1S	1S	1S	15S	XX	XX	XX	XX	15S
8y8y	1S	1S	1S	15S	XX	.64S	XX	.64S	15.64S
8y8o	1S	1S	1S	15S	XX	.128S	XX	.128S	15.128S
8yTC	1S	1S	1S	15S	XX	XX	XX	XX	15S
8o8o	1S	1S	1S	15S	XX	.0256S	XX	.0256S	15.0256S
8oTC	1S	1S	1S	15S	XX	XX	XX	XX	15S
TCx2	1S	1S	1S	15S	XX	XX	XX	XX	15S

Table C.7. Conversion of formulas to link strengths for individuals assigned to the same dwelling, same household and same boat

Occ Pair	**Strength Formula (column 10, table 1)**	**Evening, Sunday**	**Total Ticks Spent in Each Building Type**			**Ticks Divided by Total per Week (42)**			**Proportion Multiplied by the Building-Specific Scale**			**Link Strength**
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
01	8F	23	23	8	XX	.5476	.1905	XX	.1095	.0491	XX	0.159
02	6.4F + 5.328SH + 1.28SA	23	29.608	6.4	XX	.705	.1524	XX	.141	.0393	XX	0.180
03	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
04	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
08y	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
08o	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
11	18F	23	23	18	XX	.5476	.4286	XX	.1095	.1104	XX	0.220
12	9.6F	23	23	9.6	XX	.5476	.2286	XX	.1095	.0589	XX	0.168
13	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
14	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
17	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
18y	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
18o	2.4F	23	23	2.4	XX	.5476	.0571	XX	.1095	.0147	XX	0.124
19	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
1 SAHD	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
1FC	18F	23	23	18	XX	.5476	.4286	XX	.1095	.1104	XX	0.220
1TC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
22	7.68F + 5.328SH + 1.0656SA	23	29.3936	7.68	XX	.6998	.1829	XX	.14	.0471	XX	0.187
23	1.28SA	23	24.28	XX	XX	.5781	XX	XX	.1156	XX	XX	0.116
24	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110

27	6.4SH + 1.28SA	23	30.68	XX	XX	.7305	XX	XX	.1461	XX	XX	0.146
28y	1.216SA	23	24.216	XX	XX	.5766	XX	XX	.1153	XX	XX	0.115
28o	1.28F + .2464SA	23	23.2464	1.28	XX	.5535	.0305	XX	.1107	.0079	XX	0.119
29	6.4SH + 1.28SA	23	30.68	XX	XX	.7305	XX	XX	.1461	XX	XX	0.146
2 SAHD	6.8SH + 1.36SA	23	31.16	XX	XX	.7419	XX	XX	.1484	XX	XX	0.148
2FC	9.6F	23	23	9.6	XX	.5476	.2286	XX	.1095	.0589	XX	0.168
2TC	1.28SA	23	24.28	XX	XX	.5781	XX	XX	.1156	XX	XX	0.116
33	15S + 2.25SA	23	25.25	XX	15	.6012	XX	.3571	.1202	XX	.0348	0.155
34	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
37	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
38y	15S + 2.05SA	23	25.05	XX	15	.5964	XX	.3571	.1193	XX	.0348	0.154
38o	15S + .42SA	23	23.42	XX	15	.5576	XX	.3571	.1115	XX	.0348	0.146
39	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
3 SAHD	2.5SA	23	25.5	XX	XX	.6071	XX	XX	.1214	XX	XX	0.121
3FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
3TC	15S + 2.25SA	23	25.25	XX	15	.6012	XX	.3571	.1202	XX	.0348	0.155
44	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
47	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
48y	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
48o	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
49	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4 SAHD	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4TC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
78y	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120

78o	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
79	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195
8y8y	15S + .64S + 2.04SA	23	25.04	XX	15.64	.5962	XX	.3724	.1192	XX	.0363	0.156
8y8o	15S + .128S + .404SA	23	23.404	XX	15.128	.5572	XX	.3602	.1114	XX	.0351	0.147
8y9	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
8y SAHD	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
8yFC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
8yTC	15S + 2.05SA	23	25.05	XX	15	.5964	XX	.3571	.1193	XX	.0348	0.154
8o8o	15S + 1.92F + .0256S + .0816SA	23	23.0816	1.92	15.0256	.5496	.0457	.3578	.1099	.0118	.0349	0.157
8o9	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
8o SAHD	.44SA	23	23.44	XX	XX	.5581	XX	XX	.1116	XX	XX	0.112
8oFC	2.4F	23	23	2.4	XX	.5476	.0571	XX	.1095	.0147	XX	0.124
8oTC	15S + .42SA	23	23.42	XX	15	.5576	XX	.3571	.1115	XX	.0348	0.146
99	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195
9 SAHD	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195

Table C.8. Conversion of formulas to link strengths for individuals assigned to the same dwelling, different household and same boat

Occ Pair	Strength Formula (column 10, table 2)	Evening, Sunday	Total Ticks Spent in Each Building Type			Ticks Divided by Total per Week (42)			Proportion Multiplied by the Building-Specific Scale			Link Strength
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
00	6.4F + 5.328SH + 2.25SA	22.25	29.828	6.4	XX	.7102	.1524	XX	.142	.0393	XX	0.181
01	8F	22.25	22.25	8	XX	.5298	.1905	XX	.106	.0491	XX	0.155
02	6.4F + 5.328SH + 1.28SA	22.25	28.858	6.4	XX	.6871	.1524	XX	.1374	.0393	XX	0.177
03	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
04	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
07	6.4SH + 2.25SA	22.25	30.9	XX	XX	.7357	XX	XX	.1471	XX	XX	0.147
08y	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
08o	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
09	6.4SH + 2.25SA	22.25	30.9	XX	XX	.7357	XX	XX	.1471	XX	XX	0.147
0 SAHD	6.8SH + 2.5SA	22.25	31.55	XX	XX	.7512	XX	XX	.1502	XX	XX	0.150
0FC	8F	22.25	22.25	8	XX	.5298	.1905	XX	.106	.0491	XX	0.155
0TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
11	18F	22.25	22.25	18	XX	.5298	.4286	XX	.106	.1104	XX	0.216
12	9.6F	22.25	22.25	9.6	XX	.5298	.2286	XX	.106	.0589	XX	0.165
13	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
14	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
17	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
18y	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
18o	2.4F	22.25	22.25	2.4	XX	.5298	.0571	XX	.106	.0147	XX	0.121
19	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106

1 SAHD	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
1FC	18F	22.25	22.25	18	XX	.5298	.4286	XX	.106	.1104	XX	0.216
1TC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
22	7.68F + 5.328SH + 1.0656SA	22.25	28.6436	7.68	XX	.6820	.1829	XX	.1364	.0471	XX	0.184
23	1.28SA	22.25	23.53	XX	XX	.5602	XX	XX	.112	XX	XX	0.112
24	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
27	6.4SH + 1.28SA	22.25	29.93	XX	XX	.7126	XX	XX	.1425	XX	XX	0.143
28y	1.216SA	22.25	23.466	XX	XX	.5587	XX	XX	.1117	XX	XX	0.112
28o	1.28F + .2464SA	22.25	22.4964	1.28	XX	.5356	.0305	XX	.1071	.0079	XX	0.115
29	6.4SH + 1.28SA	22.25	29.93	XX	XX	.7126	XX	XX	.1425	XX	XX	0.143
2 SAHD	6.8SH + 1.36SA	22.25	30.41	XX	XX	.7240	XX	XX	.1448	XX	XX	0.145
2FC	9.6F	22.25	22.25	9.6	XX	.5298	.2286	XX	.106	.0589	XX	0.165
2TC	1.28SA	22.25	23.53	XX	XX	.5602	XX	XX	.112	XX	XX	0.112
33	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.151
34	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
37	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
38y	15S + 2.05SA	22.25	24.3	XX	15	.5786	XX	.3571	.1157	XX	.0348	0.151
38o	15S + .42SA	22.25	22.67	XX	15	.5398	XX	.3571	.108	XX	.0348	0.143
39	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
3 SAHD	2.5SA	22.25	24.75	XX	XX	.5893	XX	XX	.1179	XX	XX	0.118
3FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
3TC	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.151
44	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
47	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106

48y	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
48o	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
49	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
4 SAHD	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
4FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
4TC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
77	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
78y	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
78o	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
79	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
7 SAHD	12.5SH + 2.5SA	22.25	37.25	XX	XX	.8869	XX	XX	.1774	XX	XX	0.177
7FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
7TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
8y8y	15.64S + 2.01SA	22.25	24.26	XX	15.64	.5776	XX	.3724	.1155	XX	.0363	0.152
8y8o	15.128S + .404SA	22.25	22.654	XX	15.128	.5394	XX	.3602	.1079	XX	.0351	0.143
8y9	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
8y SAHD	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
8yFC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
8yTC	15S + 2.05SA	22.25	24.3	XX	15	.5786	XX	.3571	.1157	XX	.0348	0.151
8o8o	15.0256S + 1.92F + .0816SA	22.25	22.3316	1.92	15.0256	.5317	.0457	.3578	.1063	.0118	.0349	0.153
8o9	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
8o SAHD	.44SA	22.25	22.69	XX	XX	.5402	XX	XX	.108	XX	XX	0.108
8oFC	2.4F	22.25	22.25	2.4	XX	.5298	.0571	XX	.106	.0147	XX	0.121

8oTC	15S + .42SA	22.25	22.67	XX	15	.5398	XX	.3571	.108	XX	.0348	0.143
99	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
9 SAHD	12.5SH + 2.5SA	22.25	37.25	XX	XX	.8869	XX	XX	.1774	XX	XX	0.177
9FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
9TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
SAHD x2	15SH + 3SA	22.25	40.25	XX	XX	.9583	XX	XX	.1917	XX	XX	0.192
SAHD FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
SAHD TC	2.5SA	22.25	24.75	XX	XX	.5893	XX	XX	.1179	XX	XX	0.118
FCx2	18F	22.25	22.25	18	XX	.5298	.4286	XX	.106	.1104	XX	0.216
FCTC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
TCx2	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.151

Table C.9. Conversion of formulas to link strengths for individuals assigned to a different dwelling but the same boat

Occ Pair	**Strength Formula (column 10, table 3)**	**Evening, Sunday**	**Total Ticks Spent in Each Building Type**			**Ticks Divided by Total per Week (42)**			**Proportion Multiplied by the Building-Specific Scale**			**Link Strength**
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
00	6.4F	XX	XX	6.4	XX	XX	.1524	XX	XX	.0393	XX	0.039
01	8F	XX	XX	8	XX	XX	.1905	XX	XX	.0491	XX	0.049
02	6.4F	XX	XX	6.4	XX	XX	.1524	XX	XX	.0393	XX	0.039
0FC	8F	XX	XX	8	XX	XX	.1905	XX	XX	.0491	XX	0.049
11	18F	XX	XX	18	XX	XX	.4286	XX	XX	.1104	XX	0.110
12	9.6F	XX	XX	9.6	XX	XX	.2286	XX	XX	.0589	XX	0.059
18o	2.4F	XX	XX	2.4	XX	XX	.0571	XX	XX	.0147	XX	0.015
1FC	18F	XX	XX	18	XX	XX	.4286	XX	XX	.1104	XX	0.110
22	7.68F	XX	XX	7.68	XX	XX	.1829	XX	XX	.0471	XX	0.047
28o	1.28F	XX	XX	1.28	XX	XX	.0305	XX	XX	.0079	XX	0.008
2FC	9.6F	XX	XX	9.6	XX	XX	.2286	XX	XX	.0589	XX	0.059
33	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
38y	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
38o	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
3TC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
8y8y	15.64S	XX	XX	XX	15.64	XX	XX	.3724	XX	XX	.0363	0.036
8y8o	15.128S	XX	XX	XX	15.128	XX	XX	.3602	XX	XX	.0351	0.035
8yTC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
8o8o	15.0256S + 1.92F	XX	XX	1.92	15.0256	XX	.0457	.3578	XX	.0118	.0349	0.047
8oFC	2.4F	XX	XX	2.4	XX	XX	.0571	XX	XX	.0147	XX	0.015
8oTC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
FCx2	18F	XX	XX	18	XX	XX	.4286	XX	XX	.1104	XX	0.110
TCx2	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035

Table C.10. Conversion of formulas to link strengths for individuals assigned to the same dwelling and household but a different boat

Occ Pair	**Strength Formula (column 10, table 4)**	**Evening, Sunday**	**Total Ticks Spent in Each Building Type**			**Ticks Divided by 42 (Total Ticks per Week)**			**Proportion Multiplied by the Building-Specific Scale**			**Link Strength**
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
01	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
02	5.328SH + 1.28SA	23	29.608	XX	XX	.7050	XX	XX	.141	XX	XX	0.141
03	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
04	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
08y	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
08o	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
11	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
12	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
13	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
14	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
17	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
18y	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
18o	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
19	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
1 SAHD	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
1FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
1TC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
22	5.328SH + 1.0656SA	23	29.3936	XX	XX	.6998	XX	XX	.14	XX	XX	0.140
23	1.28SA	23	24.28	XX	XX	.5781	XX	XX	.1156	XX	XX	0.116
24	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
27	6.4SH + 1.28SA	23	30.68	XX	XX	.7305	XX	XX	.1461	XX	XX	0.146
28y	1.216SA	23	24.216	XX	XX	.5766	XX	XX	.1153	XX	XX	0.115

28o	.2464SA	23	23.2464	XX	XX	.5535	XX	XX	.1107	XX	XX	0.111
29	6.4SH + 1.28SA	23	30.68	XX	XX	.7305	XX	XX	.1461	XX	XX	0.146
2 SAHD	6.8SH + 1.36SA	23	31.16	XX	XX	.7419	XX	XX	.1484	XX	XX	0.148
2FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
2TC	1.28SA	23	24.28	XX	XX	.5781	XX	XX	.1156	XX	XX	0.116
33	15S + 2.25SA	23	25.25	XX	15	.6012	XX	.3571	.1202	XX	.0348	0.155
34	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
37	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
38y	15S + 2.05SA	23	25.05	XX	15	.5964	XX	.3571	.1193	XX	.0348	0.154
38o	15S +.42SA	23	23.42	XX	15	.5576	XX	.3571	.1115	XX	.0348	0.146
39	2.25SA	23	25.25	XX	XX	.6012	XX	XX	.1202	XX	XX	0.120
3 SAHD	2.5SA	23	25.5	XX	XX	.6071	XX	XX	.1214	XX	XX	0.121
3FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
3TC	15S + 2.25SA	23	25.25	XX	15	.6012	XX	.3571	.1202	XX	.0348	0.155
44	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
47	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
48y	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
48o	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
49	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4 SAHD	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4FC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
4TC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
78y	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
78o	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
79	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195

8y8y	15.64S + 2.04SA	23	25.04	XX	15.64	.5962	XX	.3724	.1192	XX	.0363	0.156
8y8o	15.128S + .404SA	23	23.404	XX	15.128	.5572	XX	.3602	.1114	XX	.0351	0.147
8y9	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
8y SAHD	2.2SA	23	25.2	XX	XX	.6	XX	XX	.12	XX	XX	0.120
8yFC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
8yTC	15S + 2.05SA	23	25.05	XX	15	.5964	XX	.3571	.1193	XX	.0348	0.154
8o8o	15.0256S + .0816SA	23	23.0816	XX	15.0256	.5496	XX	.3578	.1099	XX	.0349	0.145
8o9	.42SA	23	23.42	XX	XX	.5576	XX	XX	.1115	XX	XX	0.112
8o SAHD	.44SA	23	23.44	XX	XX	.5581	XX	XX	.1116	XX	XX	0.112
8oFC	XX	23	23	XX	XX	.5476	XX	XX	.1095	XX	XX	0.110
8oTC	15S + .42SA	23	23.42	XX	15	.5576	XX	.3571	.1115	XX	.0348	0.146
99	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195
9 SAHD	15SH + 3SA	23	41	XX	XX	.9762	XX	XX	.1952	XX	XX	0.195

Table C.11. Conversion of formulas to link strengths for individuals assigned to the same dwelling, different household and different boat

Occ Pair	**Strength Formula (column 10, table 5)**	**Evening, Sunday**	**Total Ticks Spent in Each Building Type**			**Ticks Divided by Total per Week (42)**			**Proportion Multiplied by the Building-Specific Scale**			**Link Strength**
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
00	5.328SH + 2.25SA	22.25	29.828	XX	XX	.7102	XX	XX	.142	XX	XX	0.142
01	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
02	5.328SH + 1.28SA	22.25	28.858	XX	XX	.6871	XX	XX	.1374	XX	XX	0.137
03	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
04	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
07	6.4SH + 2.25SA	22.25	30.9	XX	XX	.7357	XX	XX	.1471	XX	XX	0.147
08y	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
08o	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
09	6.4SH + 2.25SA	22.25	30.9	XX	XX	.7357	XX	XX	.1471	XX	XX	0.147
0 SAHD	6.8SH + 2.5SA	22.25	31.55	XX	XX	.7512	XX	XX	.1502	XX	XX	0.150
0FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
0TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
11	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
12	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
13	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
14	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
17	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
18y	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
18o	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
19	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
1 SAHD	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106

1FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
1TC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
22	5.328SH + 1.0656SA	22.25	28.6436	XX	XX	.682	XX	XX	.1364	XX	XX	0.136
23	1.28SA	22.25	23.53	XX	XX	.5602	XX	XX	.112	XX	XX	0.112
24	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
27	6.4SH + 1.28SA	22.25	29.93	XX	XX	.7126	XX	XX	.1425	XX	XX	0.143
28y	1.216SA	22.25	23.466	XX	XX	.5587	XX	XX	.1117	XX	XX	0.112
28o	.2464SA	22.25	22.4964	XX	XX	.5356	XX	XX	.1071	XX	XX	0.107
29	6.4SH + 1.28SA	22.25	29.93	XX	XX	.7126	XX	XX	.1425	XX	XX	0.143
2 SAHD	6.8SH + 1.36SA	22.25	30.41	XX	XX	.724	XX	XX	.1448	XX	XX	0.145
2FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
2TC	1.28SA	22.25	23.53	XX	XX	.5602	XX	XX	.112	XX	XX	0.112
33	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.474
34	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
37	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
38y	15S + 2.05SA	22.25	24.3	XX	15	.5786	XX	.3571	.1157	XX	.0348	0.473
38o	15S + .42SA	22.25	22.67	XX	15	.5398	XX	.3571	.108	XX	.0348	0.465
39	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
3 SAHD	2.5SA	22.25	24.75	XX	XX	.5893	XX	XX	.1179	XX	XX	0.118
3FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
3TC	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.474
44	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
47	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
48y	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
48o	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
49	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106

4 SAHD	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
4FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
4TC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
77	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
78y	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
78o	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
79	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
7 SAHD	12.5SH + 2.5SA	22.25	37.25	XX	XX	.8869	XX	XX	.1774	XX	XX	0.177
7FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
7TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
8y8y	15.64S + 2.01SA	22.25	24.26	XX	15.64	.5776	XX	.3724	.1155	XX	.0363	0.488
8y8o	15.128S + .404SA	22.25	22.654	XX	15.128	.5394	XX	.3602	.1079	XX	.0351	0.468
8y9	2.05SA	22.25	24.3	XX	XX	.5786	XX	XX	.1157	XX	XX	0.116
8y SAHD	2.1SA	22.25	24.35	XX	XX	.5798	XX	XX	.116	XX	XX	0.116
8yFC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
8yTC	15S + 2.05SA	22.25	24.3	XX	15	.5786	XX	.3571	.1157	XX	.0348	0.473
8o8o	15.0256S + .0816SA	22.25	22.3316	XX	15.0256	.5317	XX	.3578	.1063	XX	.0349	0.464
8o9	.42SA	22.25	22.67	XX	XX	.5398	XX	XX	.108	XX	XX	0.108
8o SAHD	.44SA	22.25	22.69	XX	XX	.5402	XX	XX	.108	XX	XX	0.108
8oFC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
8oTC	15S + .42SA	22.25	22.67	XX	15	.5398	XX	.3571	.108	XX	.0348	0.465
99	11.25SH + 2.25SA	22.25	35.75	XX	XX	.8512	XX	XX	.1702	XX	XX	0.170
9 SAHD	12.5SH + 2.5SA	22.25	37.25	XX	XX	.8869	XX	XX	.1774	XX	XX	0.177

9FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
9TC	2.25SA	22.25	24.5	XX	XX	.5833	XX	XX	.1167	XX	XX	0.117
SAHD x2	15SH + 3SA	22.25	40.25	XX	XX	.9583	XX	XX	.1917	XX	XX	0.192
SAHD FC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
SAHD TC	2.5SA	22.25	24.75	XX	XX	.5893	XX	XX	.1179	XX	XX	0.118
FCx2	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
FCTC	XX	22.25	22.25	XX	XX	.5298	XX	XX	.106	XX	XX	0.106
TCx2	15S + 2.25SA	22.25	24.5	XX	15	.5833	XX	.3571	.1167	XX	.0348	0.474

Table C.12. Conversion of formulas to link strengths for individuals assigned to different dwellings and different boats

Occ Pair	Strength Formula (column 10, table 6)	Evening, Sunday	Total Ticks Spent in Each Building Type			Ticks Divided by Total per Week (42)			Proportion Multiplied by the Building-Specific Scale			Link Strength
			Dwelling	*Boat*	*School*	*Dwelling*	*Boat*	*School*	*Dwelling*	*Boat*	*School*	
33	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
38y	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
38o	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
3TC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
8y8y	15.64S	XX	XX	XX	15.64	XX	XX	.3724	XX	XX	.0363	0.036
8y8o	15.128S	XX	XX	XX	15.128	XX	XX	.3602	XX	XX	.0351	0.035
8yTC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
8o8o	15.0256S	XX	XX	XX	15.0256	XX	XX	.3578	XX	XX	.0349	0.035
8oTC	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035
TCx2	15S	XX	XX	XX	15	XX	XX	.3571	XX	XX	.0348	0.035

APPENDIX D – RESULTS OF T-TESTS CONDUCTED FOR COMPARING EPIDEMIC OUTCOMES AMONG DEMOGRAPHIC SUBGROUPS

The tables in this appendix provide details on the ad-hoc t-tests conducted for all ANOVA tests described in Chapter 8. All analyses used Microsoft Excel to conduct two-sample tests assuming unequal variances (unless otherwise noted), and an alpha level of 0.05. Columns labeled N/A indicate that no significant difference was found in the ANOVA and therefore no ad hoc t-tests were conducted. Numbers in the parentheses beneath each result indicate the degrees of freedom for that comparison. Results marked with an asterisk indicate a statistically significant difference between the pair. Positive or negative signs indicate the direction of difference between group means; actual means are included in the ANOVA results presented in Chapter 8, and the title of each table here references the corresponding ANOVA table.

Table D.1. t-Test results for epidemic outcomes varying the group of the first case, ABM (see Table 8.1)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Final Proportion (Degrees of Freedom)[a]	t-Test Results For Peak Proportion (Degrees of Freedom)[a]	t-Test Results for Peak Day (Degrees of Freedom)	t-Test Results for Last Day (Degrees of Freedom)
1 - 2	-0.16 (468)	-0.29 (472)	1.05 (471)	N/A
1 - 7/9	0.23 (395)	-0.17 (403)	0.43 (426)	
1 - 8	-2.32* (503)	-3.86* (518)	4.03* (409)	
2 - 7/9	0.37 (408)	0.10 (396)	-0.67 (420)	
2 - 8	-2.03* (468)	-3.60* (519)	2.92* (421)	
7/9 - 8	-2.34* (365)	-3.40* (393)	3.80* (358)	

Table D.2. t-Test results for epidemic outcomes varying the group of the first case, SN model (see Table 8.1)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Final Proportion (Degrees of Freedom)[a]	t-Test Results For Peak Proportion (Degrees of Freedom)[a]	t-Test Results for Peak Day (Degrees of Freedom)	t-Test Results for Last Day (Degrees of Freedom)
1 - 2	2.87* (559)	1.85 (559)	0.40 (527)	1.95 (536)
1 - 7/9	-0.20 (521)	-0.51 (521)	-2.56* (453)	-1.40 (479)
1 - 8	-1.02 (650)	-1.33 (650)	0.33 (624)	-0.13 (618)
2 - 7/9	-2.93* (478)	-2.20* (478)	-2.74* (469)	-3.14* (474)
2 - 8	-4.02* (607)	-3.14* (607)	-0.13 (506)	-2.20* (512)
7/9 - 8	-0.75 (569)	-0.70 (569)	2.96* (422)	1.36 (446)

[a] t-test analyses assume equal variances

Table D.3. t-Test results for group-specific outcomes in simulations with fishermen as the first case, ABM (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	N/A	1.93 (474)
1 - 7/9		4.09* (462)
1 - 8		-5.68* (401)
2 - 7/9		2.13* (469)
2 - 8		-7.21* (387)
7/9 - 8		-8.91* (361)

Table D.4. t-Test results for group-specific outcomes in simulations with fisherwomen as the first case, ABM (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-0.59 (438)	3.03* (459)
1 - 7/9	-2.21* (436)	4.53* (465)
1 - 8	0.52 (448)	-4.63* (393)
2 - 7/9	-1.49 (423)	1.69 (466)
2 - 8	1.09 (421)	-7.01* (361)
7/9 - 8	2.74* (418)	-8.07* (374)

Table D.5. t-Test results for group-specific outcomes in simulations with mothers as the first case, ABM (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-2.38* (320)	2.65* (374)
1 - 7/9	1.09 (364)	3.39* (361)
1 - 8	2.66* (358)	-4.66* (331)
2 - 7/9	3.30* (329)	0.60 (369)
2 - 8	4.85* (303)	-6.84* (318)
7/9 - 8	1.42 (353)	-7.54* (293)

Table D.6. t-Test results for group-specific outcomes in simulations with schoolchildren as the first case, ABM (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-1.90 (624)	2.61* (682)
1 - 7/9	0.29 (662)	3.53* (676)
1 - 8	8.11* (668)	-9.82* (613)
2 - 7/9	2.12* (629)	0.83 (677)
2 - 8	9.34* (627)	-11.98* (609)
7/9 - 8	7.60* (659)	-12.95* (581)

Table D.7. t-Test results for group-specific outcomes in simulations with fishermen as the first case, SN model (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-1.27 (550)	0.72 (602)
1 - 7/9	-3.59* (557)	3.71* (596)
1 - 8	-0.93 (568)	-4.32* (513)
2 - 7/9	-2.12* (531)	2.94* (595)
2 - 8	0.43 (522)	-4.87* (516)
7/9 - 8	2.76* (528)	-7.23* (484)

Table D.8. t-Test results for group-specific outcomes in simulations with fisherwomen as the first case, SN model (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	0.08 (487)	2.22* (510)
1 - 7/9	-3.49* (415)	4.63* (505)
1 - 8	-1.22 (470)	-2.39* (454)
2 - 7/9	-3.41* (430)	2.51* (515)
2 - 8	-1.23 (458)	-4.20* (426)
7/9 - 8	2.40* (403)	-6.07* (417)

Table D.9. t-Test results for group-specific outcomes in simulations with mothers as the first case, SN model (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-2.96* (380)	1.84 (440)
1 - 7/9	-0.01 (426)	4.05* (425)
1 - 8	0.90 (422)	-4.87* (372)
2 - 7/9	2.81* (395)	2.09* (428)
2 - 8	3.71* (382)	-6.28* (367)
7/9 - 8	0.86 (419)	-8.05* (332)

Table D.10. t-Test results for group-specific outcomes in simulations with schoolchildren as the first case, SN model (see Tables 8.2 and 8.3)

Group (Occ-type) Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	-3.30* (570)	1.91 (697)
1 - 7/9	-0.29 (663)	3.50* (679)
1 - 8	6.10* (673)	-7.09* (611)
2 - 7/9	2.98* (577)	1.38 (672)
2 - 8	8.77* (540)	-8.54* (621)
7/9 - 8	6.24* (649)	-10.11* (553)

Table D.11. t-Test results for outcomes for fishermen varying the group of the first case, ABM (see Table 8.4)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	N/A	N/A
1 - 7/9		
1 - 8		
2 - 7/9		
2 - 8		
7/9 - 8		

Table D.12. t-Test results for outcomes for fishermen varying the group of the first case, SN model (see Table 8.4)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	0.98 (535)	N/A
1 - 7/9	-2.64* (467)	
1 - 8	-1.94 (616)	
2 - 7/9	-3.41* (467)	
2 - 8	-2.84* (516)	
7/9 - 8	1.04 (437)	

Table D.13. t-Test results for outcomes for fisherwomen varying the group of the first case, ABM (see Table 8.5)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	0.75 (430)	N/A
1 - 7/9	-2.27* (343)	
1 - 8	1.10 (397)	
2 - 7/9	-2.91* (354)	
2 - 8	0.18 (379)	
7/9 - 8	3.59* (267)	

Table D.14. t-Test results for outcomes for fisherwomen varying the group of the first case, SN model (see Table 8.5)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	2.08* (498)	3.50* (559)
1 - 7/9	-4.19* (390)	1.01 (489)
1 - 8	-3.33* (549)	0.66 (640)
2 - 7/9	-5.87* (401)	-2.27* (450)
2 - 8	-5.29* (497)	-2.91* (597)
7/9 - 8	1.39 (379)	-0.41 (495)

Table D.15. t-Test results for outcomes for mothers varying the group of the first case, ABM (see Table 8.6)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	0.37 (427)	-0.02 (461)
1 - 7/9	2.31* (392)	-0.13 (399)
1 - 8	4.31* (397)	-2.94* (536)
2 - 7/9	1.90 (387)	-0.10 (418)
2 - 8	3.72* (360)	-2.67* (481)
7/9 - 8	1.34 (311)	-2.57* (405)

Table D.16. t-Test results for outcomes for mothers varying the group of the first case, SN model (see Table 8.6)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	N/A	3.21* (556)
1 - 7/9		0.44 (502)
1 - 8		-1.14 (621)
2 - 7/9		-2.71* (471)
2 - 8		-4.56* (559)
7/9 - 8		-1.58 (486)

Table D.17. t-Test results for outcomes for schoolchildren varying the group of the first case, ABM (see Table 8.7)

Group (Occ-type) of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	1.37 (427)	0.12 (470)
1 - 7/9	2.17* (386)	0.33 (407)
1 - 8	8.42* (407)	-2.75* (472)
2 - 7/9	0.74 (390)	0.21 (413)
2 - 8	6.45* (384)	-2.77* (445)
7/9 - 8	5.77* (336)	-2.94* (356)

Table D.18. t-Test results for outcomes for schoolchildren varying the group of the first case, SN model (see Table 8.7)

Occupation of First Case Pairwise Comparisons	t-Test Results for Average Day Infected (Degrees of Freedom)	t-Test Results for Average Proportion Infected (Degrees of Freedom)
1 - 2	0.53 (451)	2.86* (556)
1 - 7/9	-0.80 (410)	-1.16 (477)
1 - 8	4.75* (556)	-2.12* (627)
2 - 7/9	-1.21 (419)	-3.81* (453)
2 - 8	3.66* (417)	-5.16* (568)
7/9 - 8	4.84* (369)	-0.73 (456)

VITA

Jessica Dimka was born in Plover, Wisconsin, to Glen and Susan Dimka. After graduating from Stevens Point Area High School in Stevens Point, Wisconsin, she attended the University of Wisconsin Madison. She earned a Bachelor of Science in Anthropology in May 2003. In May 2005, she earned a post-baccalaureate certificate in Death Investigation from the University of Wisconsin Milwaukee.

She started graduate work in Anthropology at California State University Chico and graduated with a Master's of Arts in 2008. While a student, she volunteered with the Physical Anthropology and Human Identification Laboratory's Forensic Recovery Team, and co-founded and served as president for the Anthropology Graduate Student Association.

In 2008, she began work on a doctoral degree in Anthropology at the University of Missouri Columbia. During her time there, she aided in the development of epidemiological models for projects of colleagues in the department, in addition to conducting her own research. She presented at multiple regional, national and international conferences, and participated in workshops and short courses at MU and other institutes across the country. She taught courses for the Anthropology and Health Sciences departments and also worked as a research assistant in Health Sciences.