AN EXPLORATION OF CLIMATE-RELEVANT DATABASES IN BRITISH COLUMBIA: LAYING THE GROUNDWORK FOR FUTURE RESEARCH ON HEALTH AND DEVELOPMENT OUTCOMES

by

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An exploration of climate-relevant databases in British Columbia: laying the groundwork for future research on health and development outcomes

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Abstract

This thesis builds on the important role that the Early Development Instrument (EDI) has played in monitoring and studying the developmental outcomes of kindergarten-aged children in British Columbia (BC), along with the social determinants of those outcomes. In spite of evidence of climate change's disproportionate global burden on children, further research is yet needed to fully understand what impact climate change may have on these developmental outcomes in BC. Furthermore, the EDI has yet to be used as an outcome of interest in research on the effects of climate change in BC. In response, this project attempted to lay the foundation for this future line of research inquiry, as well as climate-exposure research with other health and development outcomes. First, a range of climate-relevant factors were selected for study. These included heat/temperature, wildfires and their smoke/particulate matter, evacuations, ground-level ozone, and floods. Next, a scoping review was conducted to assemble a comprehensive list of climate-relevant databases that have been used in BC in the same range of years as the EDI. A set of criteria was established to evaluate the databases, thereby determining which would be most appropriate for studying associations with early developmental outcomes as assessed by the EDI.

The most promising database found for studying ECD in conjunction with heat/temperature is Environment and Climate Change Canada's temperature database. For studies with wildfires, the Canadian National Fire Database is the most promising. For studying smoke or particulate matter, there is not one single database that is the most promising. However, the Canadian Urban Environmental Research Consortium, Firework, and the BC Centre for Disease Control's Optimized Statistical Smoke Exposure Model could all be used to answer different questions. For studying evacuations, Natural Resources Canada's Wildland Fire Evacuation Database is the most promising. For studying ozone, the most promising databases are the Ministry of

Environment and Climate Change air quality network (which collaborates with Metro Vancouver Air Quality), and CANUE. The most promising database found for flooding was the National Water Data Archive. The project concluded with a discussion of what hypotheses are testable based on these promising climate-relevant databases.

Lay Summary

This thesis project aimed to identify data resources that could be used in concert with health and development data to test hypotheses about the association between climate change and health outcomes in British Columbia (BC), with a particular focus on early child development guided by the collection of Early Development Instrument (EDI) data. Developing an understanding of the current availability of climate-relevant data was at the centre of this project's work. Specifically, data on the effects of climate change that are most likely to occur in BC were sought. A literature search was done to gather a complete list of databases that have published research on these effects in BC. The databases were then assessed to determine which would be the most promising for studying in association with the EDI, and for generating future hypotheses. The project concludes with directions for future research based on these promising databases.

Preface

During this thesis project, Kevin Bouliane applied for ethical approval from the University of British Columbia (UBC) Behavioural Research Ethics Board under the project title *A Review of Selected Climate-Relevant Research in BC from 2001-2020*. Approval was granted on January 5th, 2021 (H20-03876).

The work presented in this thesis was conducted under the supervision of Dr. Paul Kershaw with guidance from the supervisory committee: Dr. Barry Forer, Dr. Kate Weinberger, and Dr. Angela Yao. The study design was conceived of by Dr. Paul Kershaw. The scoping review was carried out by Kevin Bouliane. Contacting the databases to gather data characteristics was done by Kevin Bouliane. Dr. Kate Weinberger and Dr. Angela Yao shared their expertise on environmental research methods. Their expertise, along with Dr. Barry Forer's experience working with the EDI, informed the evaluation of promising databases. The thesis writing was completed by Kevin Bouliane and was reviewed by all committee members.

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To all young ones, in body and in spirit.

Chapter 1: Introduction

1.1 Context

Climate change has been described as the biggest global health threat of the 21st century by the Lancet Countdown, which annually tracks the progress being made on addressing climate change, and how climate change translates into health risks (Watts et al., 2018). Without sufficient mitigation efforts, children born today are expected to experience a world that is four degrees Celsius warmer than the pre-industrial level (Watts et al., 2019). Children are also among the demographics most significantly impacted by climate change (Watts et al., 2019). Globally, the most evident reasons for this heightened impact include increasing threats to food production and security which disproportionately affect infants; diarrhoeal disease, for which children are among the most susceptible; and dengue fever, which affects children more severely (Watts et al., 2019). These maladies represent acute threats to children, but they may not reflect the full scope of impacts of climate change on children.

As climate change advances, it will be important to study its effects on health generally, including those specific to child development in Canada. This is because research has shown that unmitigated childhood adversity and vulnerability are associated with challenges in learning, behaviour, and health outcomes (Felitti et al., 1998; Shonkoff, J. P. et al., 2011). These highly consequential early years of development are always important to monitor, but this may be especially true as climate change advances with challenges that have potential to disrupt optimal trajectories of development. With more comprehensive research into the effects of climate change on child development, leaders in all domains of society will be more informed and better prepared to protect this early development.

One tool that has been used to holistically measure early child development (ECD) is the Early Development Instrument (EDI). The EDI is a questionnaire that is administered by teachers in British Columbia (BC), throughout Canada, and internationally. It measures five core domains of child development in kindergarten-aged children, and is guided by a scientific understanding of the sensitive and impactful nature of this phase of human development. Its five domains are known to be good predictors of later education and social outcomes (Duncan, Duncan, Stanley, Aguilar, & Halfon, 2020; Thomson et al., 2019). The EDI is used to study ECD, guide decision-making, and promote multidisciplinary policies and investments that are associated with greater well-being of both children and of the communities in which they reside.

In BC, the EDI has given policymakers, planners, administrators, and community ECD partners in multiple sectors useful information about the state of ECD in BC since 2004 via two- or three-year waves of data collection. However, the EDI has yet to be utilized to answer questions about the relationship with climate change. The significance and sensitivity of ECD, juxtaposed by the forecasted threats of climate change in BC, present a substantial emerging opportunity to study this interface moving forward. The EDI has potential to be an important tool in this line of inquiry, but the climate-relevant databases that would be needed for this have not yet been identified or evaluated based on their alignment with EDI data.

The objective of this thesis project was to identify climate-relevant data resources that could be used in concert with the EDI and other health and development data to test hypotheses about the relationship between climate-relevant exposures and health outcomes. In doing so, this exploratory project is intended to lay the foundation for future research on ECD and other health-relevant domains by identifying promising climate-relevant databases. Given this project was motivated by the specific goal to facilitate future research about the impact of climate change on

child development using the EDI, discussion of the EDI is in focus throughout. However, this thesis was not intended to develop a comprehensive theoretical framework that hypothesizes various pathways by which climate-relevant factors may influence early development. Such frameworks would need to be provided by researchers in the future who aim to take advantage of the datasets identified and described in this thesis.

This project pursued its objective by exploring what climate-relevant databases exist in BC, and how the data they store may be used to analyze associations with EDI data collected for BC. In BC, extreme heat, wildfires, floods, and air pollution are some of the likely factors related to climate change that may impact human health (Ostry, Ogborn, Bassil, Takaro, & Allen, 2010). Therefore, these were chosen as primary climate-relevant factors (CRFs) for this project. Regional evacuations – in which a neighbourhood, community, or larger area is deemed at least temporarily unsafe for habitation – are also major stressors that are associated with environmental exposures such as floods and fires (Buttle et al., 2016; Beverly & Bothwell, 2011). Therefore, these were included as CRFs as well. Evacuations are not environmental exposures themselves, but may be thought of as an added layer of stress, compounding that of other CRFs. In this project, evacuations were nevertheless grouped together with the other CRFs. This is because the aim of this project was to gather CRF data resources and provide directions for future CRF-EDI research, but not to propose how CRFs may be analyzed in relation to one another.

Understanding what data have been continuously collected in a similar timeframe as the EDI will guide future research on the associations between these factors. This study focused on the spatial and temporal patterns available for CRF data to inform future hypothesis generation about the relationship between climate change in BC and its influence on child development.

1.2 Climate Change - General

Climate change is characterized in part by the gradual increase in Earth's temperature, caused by increasing atmospheric concentrations of carbon dioxide, methane, and nitrous oxide (Friel & Krieger, 2018), among others. In Canada, the rate of this warming is more than double the global rate (Natural Resources Canada, 2019). This is expected to lead to various downstream environmental impacts, including droughts, storms, flooding, sea level rise, ocean acidification, species extinction, and food insecurity. These far-reaching disruptions to Earth's natural systems impact regions differently, and in turn affect populations differently.

1.2.1 Climate Change – Impacts on Health

Climate change is a complex and multifaceted phenomenon. It is thought to impact human health through several different pathways: direct effects, indirect effects mediated through natural systems, and indirect effects mediated through human systems (Smith, K. et al., 2014). Direct effects include extreme weather such as heat and flood exposure. Indirect effects mediated through natural systems include allergens, disease vectors, and pollution of air and water. Finally, indirect effects mediated through human systems include mental stress and challenges in the production and distribution of food. The range of different effects of climate change makes its reach incredibly broad. Furthermore, while climate change can affect anyone, it disproportionately impacts those who are already marginalized in society (Hayes & Poland, 2018). This is why climate change has been referred to as a health threat multiplier (Olson & Metz, 2020). An example of this phenomenon is its impact on children. Globally, children under the age of 5 years old are estimated to bear 88% of the burden of disease due to climate change, and this will be disproportionately felt by the poorest among them (Philipsborn & Chan, 2018).

While climate change is already manifesting itself and impacting the health of Canadians, it is predicted to advance substantially in the coming decades (Watts et al., 2019). The health impacts of climate change are expected to be diverse and far-reaching (Lesnikowski et al., 2011). The predominant climate-relevant factors that are expected to influence health in BC are presented below, with a focus on their general health effects.

1.2.2 Heat/Temperature

Exposure to extreme heat acutely affects individuals with increasingly severe harm as temperatures climb. When the body's temperature reaches 38℃, physical and cognitive functions are impaired (Smith et al., 2014). At 40.6℃ and above, risks of organ damage, loss of consciousness, and death increase dramatically. In addition to illness and death directly due to heat-related conditions, periods of extreme heat can lead to a range of other maladies. In older adults, extreme heat has been associated with increased risk of hospitalization for fluid and electrolyte disorders, renal failure, urinary tract infections, and septicemia (Bobb, Obermeyer, Wang, & Dominici, 2014). However, young children have also been identified as vulnerable to heat exposure (Basu, 2009; Basu & Ostro, 2008). The connection between heatwaves and mortality in children is inconsistent, but persistent hot episodes do increase the risk of children experiencing respiratory disease, renal disease, and electrolyte imbalance (Xu, Sheffield, Su, Wang, & Bi, 2014).

Health risks associated with heat extend beyond acute exposure to extreme heat. Average temperature as well as temperature variability also impact human health. Increased variability in temperatures has been shown to increase deaths beyond what would be expected from increasing average temperatures alone (Gosling, McGregor, & Lowe, 2008).

1.2.3 Wildfires

Heat in combination with low levels of precipitation can result in wildfires, which have a range of downstream effects. British Columbia experienced widespread wildfires in both 2017 and 2018 (Xu Rongbin et al., 2020), prompting the declaration of a provincial state of emergency in both years (BC Wildfire Service, 2020). As climate change worsens, an increase in the risk of wildfires is predicted (Xu Rongbin et al., 2020). Directly, wildfires cause deaths from burns and injury (Silk, Ann W., MD, MS & Margolin, 2018). Indirectly, wildfire smoke has also been associated with increased morbidity and mortality. When wildfires are not successfully contained, they can devastate entire communities. In such circumstances, even if injuries and smoke inhalation are avoided, homes, businesses, community resources, and other vital infrastructure may be lost or damaged. These tragedies subject residents to a long list of potential challenges, including geographic displacement, food and water scarcity, financial hardship, and emotional trauma.

1.2.4 Air Pollution – General

Ambient (outdoor) air pollution is a major public health threat. It accounts for 4.2 million deaths worldwide each year (World Health Organization, 2020). While low- and middle-income countries are affected the worst, nearly everyone on Earth experiences some degree of air pollution, as the World Health Organization (WHO) estimates that 91% of the world's population lives in places where the air quality exceeds its guidelines. Health Canada estimates that "above-background air pollution, including air pollution from human sources in North America, contributes to 15,300 premature deaths per year in Canada…[including] 1900 in British Columbia" (Health Canada, 2021).

Air pollution comes in various forms. Depending on the form, it can be seen as both a cause and as an effect of climate change. The two air pollution sources of principal interest in this project were wildfire smoke and ground-level ozone.

1.2.5 Air Pollution – Wildfire Smoke

While wildfires are not all caused by climate change, there is projected to be an increased risk of wildfires as climate change worsens (Xu Rongbin et al., 2020). Therefore, wildfire smoke may be seen as an effect of climate change that threatens human health. It threatens health in various ways. Heavy smoke can cause eye irritation and corneal abrasions (Xu Rongbin et al., 2020). It also impairs visibility which may increase the risk of motor vehicle collisions (Xu Rongbin et al., 2020). However, the primary health-impairing pathway of wildfire smoke is through inhalation. Inhalable pollutants produced from wildfires include particulate matter (PM), carbon monoxide, nitrogen dioxide, nitric oxide, volatile organic compounds, and ground-level ozone. In relation to wildfires studied in this project, particulate matter was the primary focus, as it is a relatively all-encompassing term that includes all particles of a given size suspended in the air (Xu Rongbin et al., 2020). While it does not distinguish between different sources of pollutants, it is a very useful measure that indicates the overall state of air quality. Particulate matter is typically studied as either PM_{10} or $PM_{2.5}$, which is the concentration of all particles equal to or less than 10 micrometres and 2.5 micrometres in diameter, respectively (Xu Rongbin et al., 2020).

In the short term, the health effects of exposure to wildfire PM are varied. There is consistent evidence of an increased risk of mortality from any cause, as well as an increased risk of hospitalizations and emergency department visits due to asthma, chronic obstructive pulmonary disease, and respiratory infections (Xu Rongbin et al., 2020). Additionally, risks of

low birth weight and preterm birth are increased, as well as the rates of influenza and ambulance dispatches for people with diabetes (Xu Rongbin et al., 2020). Focusing now on birth outcomes, low birth weight is positively associated with respiratory problems, asthma, and poor cognitive development during infancy and childhood (Campbell et al., 2018), as well as an increased risk of motor problems in adolescence (Evensen et al., 2004) Collectively, the evidence of the health risks of wildfire smoke exposure should motivate ongoing, focused monitoring of the effects it may have on ECD in BC. This is especially significant in the context of BC's vast wildfires and the forecast of more to come with advancing climate change.

1.2.6 Air Pollution – Ozone

Ozone is a gas that forms a layer in the stratosphere of Earth's atmosphere (Chen, Kuschner, Gokhale, & Shofer, 2007). At this altitude, it protects humans from the sun's harmful ultraviolet radiation. When ozone is present in the troposphere which is lower, it is known as ground-level ozone – measured in parts per billion (ppb) – and it is harmful to humans, acting as a respiratory irritant. Tropospheric ozone is produced when nitrogen oxides released from the burning of fossil fuels react with volatile organic compounds from gasoline and solvents. Free oxygen atoms are released from these reactions, which then bind with molecular oxygen to form ozone. Ozone exposure is associated with dyspnea, upper airway irritation, coughing, chest tightness, diagnosis of asthma (Chen et al., 2007), and exacerbation of asthma (Li et al., 2019). This ozone-driven exacerbation of asthma has life-altering implications for children. Children with asthma are at high risk of developmental, emotional, and behavioural problems (Blackman & Gurka, 2007). The evidence of ozone's harmful effects warrants further study of its effect on ECD.

1.2.7 Floods

Floods impact human health through drowning, hypothermia, injury, vehicle-related incidents, and infectious diseases due to water contamination (Paranjothy et al., 2011; Jakubicka, Vos, Phalkey, & Marx, 2010; Schnitzler, Benzler, Altmann, Mucke, & Krause, 2007). If victims of flooding escape these immediate threats, they may still suffer mental health challenges. The residents of a community overwhelmed with water are naturally subjected to an increased risk for mental health insults, including psychological distress, anxiety, depression, and post-traumatic stress disorder (PTSD) (Paranjothy et al., 2011). Perceived financial hardship from floods, disrupted access to essential services, and evacuations exacerbate these mental health risks. These acute stressors may persist well past the event as well. There is evidence of an association between displacement due to flooding and symptoms of depression, anxiety, and post-traumatic stress one year after the event, especially when a flood warning is not received (Tong, 2017).

In summary, this section (1.2) offered an introduction to climate change, its connection to human health, and its disproportionate global impact on children. Each of the CRFs that are in focus for this project were introduced individually, with emphasis placed on their health effects. This was intended to reinforce the seriousness of the threat of climate change. The following section (1.3) shifts focus toward children, with an overview of some of the physiological reasons for children's unique level of sensitivity to their environments.

1.3 Early Child Development

1.3.1 Childhood Biological Sensitivity to Environment

By the first five years of life, the development of a child has already been influenced strongly by the family, but also by neighbourhood and societal factors (Maggi, Irwin, Siddiqi, & Hertzman, 2010). These non-medical factors influencing health and the conditions in which

children are raised are known as the social determinants of health. They represent the broader systems and policies that shape the lives of populations, and may be even more potent than lifestyle choices when it comes to influencing health. Among others, the social determinants of health include income and social protection, education, food security, housing, social inclusion, levels of structural conflict, access to health services, and the environment (World Health Organization, 2021). This means that human-influenced climate change is a key social and ecological determinant of health for people throughout their life course.

Social and ecological factors influence human health in part through biological embedding. This is the process whereby human experience alters biological processes in stable and long-term ways that influence health over the life course (Hertzman & Boyce, 2010). Human biology is especially sensitive to its environment in the early years.

Evidence of biological embedding emerged from research on the hypothalamic-pituitary-adrenal (HPA) axis (Hertzman, 1999). The HPA axis is central in the process of perceiving and responding to stressful stimuli, in part by releasing the hormone cortisol, which has metabolic effects on organs throughout the body. One study showed that toddlers who had poor attachments to their mothers had more reactive HPA axes and less adaptive behavioural responses to circumstances of social conflict (Gunnar & Nelson, 1994). The stress response as a whole increases heart rate and blood pressure, protectively mobilizes nutrients, redirects blood perfusion to the brain, and elicits the subjective feeling of vigilance and fear (Shonkoff et al., 2009; Braveman Paula & Barclay Colleen, 2009). This stress response is vital, and it responds effectively to acute threats, but it can become harmful when the stressor is chronic or overwhelming.

The mechanisms that underlie biological embedding are not fully understood, but one line of hypotheses focuses on epigenetic processes (Essex et al., 2013). Epigenetic science is "the study of stable alterations in gene expression by nongenomic mechanisms, resulting in stable alterations in phenotypes" (Essex et al., 2013). These changes may be responsible for developmental alterations in growth, metabolism, immune responsiveness, developmental pace, and behaviour. This line of research is still emerging, but there is evidence of associations between early life stress and long-term DNA changes (Essex et al., 2013). Further research may yet demonstrate whether this stress is a pathway by which CRF exposures influence long-term health outcomes.

The growing recognition of the interconnectedness of one's early life experiences with long-term life course trajectories is central to this project. It is the foundational rationale for considering what impact the phenomenon of climate change may have on ECD in BC, and for conducting the preliminary research that will facilitate this inquiry. Climate-relevant databases were sought during this project with the specific objective of pairing them with ECD data because of the evidence of the significance of early years.

Vulnerability to climate change during one's early years manifests in various forms. Some of the most commonly studied child-specific, climate-sensitive health risks include infectious diseases, inadequate availability of quality food and water, air contaminants, extreme weather, and population displacement (Sheffield & Landrigan, 2011). The inherent susceptibility to the contents and forces of the proximate environment in childhood is of particular relevance in light of the looming threat of climate change.

Children have various biological differences from adults that may make them especially vulnerable to their environmental exposures. First, children have metabolic and physiological

differences that make extreme heat exposures more dangerous (Sheffield & Landrigan, 2011). Children also experience rapid early development, which makes vector-borne diseases, toxins, and undernutrition especially harmful at younger ages (Sheffield & Landrigan, 2011). Due to children's smaller size, they have greater exposures per unit of body weight, meaning toxins that are ingested or inhaled may stress the bodies of children more than adults (Sheffield & Landrigan, 2011).

Together, these physiological differences of children demonstrate an increase in their vulnerability to environmental hazards relative to adults. Children may be exposed to the effects of climate change directly (eg. regularly breathing harmful airborne pollutants) or indirectly (eg. experiencing a lack of basic resources due to their community being inaccessible or because they were required to evacuate). These exposures may not only acutely damage their health and well-being, but may have long-term consequences relative to children in other communities or to children in previous generations who did not have to contend with these environmental hazards at a young and vulnerable age. This fact underscores the significance of the early years of life and provides justification for future inquiry into the climate change-ECD relationship in order to protect future cohorts and generations of children.

1.3.2 Impacts of Climate Change on Children

The biological sensitivity of children that is discussed above (section 1.3.1) contributes to the serious harm that climate change has inflicted, and is expected to continue to impose, on children, including mortalities. Globally, the common causes of pediatric deaths due to climate-sensitive health threats include diarrhea, malaria, and nutritional deficiencies (Philipsborn & Chan, 2018). However, the vulnerability of young children to climate change extends beyond acute physical harm. Climate change also puts children at risk of post-traumatic stress disorder

(PTSD), depression, anxiety, phobias, sleep disorders, attachment disorders, and substance abuse (Olson & Metz, 2020). These conditions can in turn lead to challenges in various domains of functioning, including emotional regulation, cognition, learning, behavior, language development, and academic performance (Olson & Metz, 2020).

In addition to older children, infants are also highly vulnerable. Exposures related to climate change have been associated with a range of adverse pregnancy outcomes, including eclampsia, preeclampsia, cataract, low birth weight, preterm birth, hypertension, sex ratio, and length (Olson & Metz, 2020). Climate change can create and exacerbate Prenatal Maternal Stress (PNMS), which leads to adverse pregnancy outcomes that can be passed through multiple generations through epigenetics, a process which is discussed in more detail later (Olson & Metz, 2020). The effects of climate change put the health, well-being, and overall potential of future generations in jeopardy, and more research is warranted to investigate these threats. In particular, climate change may adversely impact early child development, with implications for lifelong trajectories of health. The importance of early child development and its potential relationship to climate change is further discussed below.

1.3.3 Long-Term Implications of Early Child Development

Given people's biological sensitivity to their environments when young, early exposures and experiences represent an impactful timeframe in which lifelong trajectories for health outcomes are shaped. Associations have been made between traumatic childhood events and a large number of subsequent health impairments and unhealthy behaviours, including coronary artery disease, chronic pulmonary disease, cancer, alcoholism, depression, drug abuse, mental health problems, obesity, physical inactivity, and smoking (Shonkoff, Jack P., Boyce, & McEwen, 2009).

Moreover, while traumatic experiences are harmful to child development, they do not represent a threshold at which harm begins. Developmental trajectories vary along social gradients, in which healthy developmental outcomes decline gradually from the most privileged to the least privileged population subgroups (Hertzman & Boyce, 2010). This means that regardless of the presence or absence of trauma, the developmental outcomes of children are inextricably tied to their lived experiences. Two different models attempt to explain the associations between early life experiences and later life implications. These are known as the latency model and the pathways model. The two models are discussed below, along with examples of how climate-relevant exposures may align with each of them.

"Latency" explanations argue that the early experiences of children exert an impact later in life, independent of intervening experiences (Shonkoff et al., 2009; Keating & Hertzman, 1999). The latency model makes reference to critical periods, which represent discrete windows of time during which the opportunity to acquire specific competencies exists. The time and duration of critical periods are unique to each competency, though they all share the characteristic of being early in life. During these critical periods, children are especially sensitive to their environments, and the absence of important stimuli is thought to impact the development of the brain both structurally and functionally, precluding the successful acquisition of their corresponding competencies (Shonkoff et al., 2009; Keating & Hertzman, 1999). This effect can also translate stressors during critical periods into disease manifestations later in life.

Climate change's impact on ECD may in fact be a disruption of important parts of a young child's life in ways that align with the latency model. In 2017 and 2018, BC experienced wildfires that were a prime example of this kind of disruption. The fires spread across the province, threatening communities and creating harmful air pollution from smoke. It is likely

that children experiencing the worst of these effects may have been kept indoors for their health and safety. Given the circumstances, this would have been a wise response. However, confinement to a predominantly indoor environment could contribute to a lack of socialization, play, physical activity, and exploration. The absence of these social, physical, and cognitive stimuli and experiences during early childhood may in fact represent a missed critical period of development, leading to latent repercussions. Indeed, there is evidence that suggests social deprivation early in life may lead to long-term regulatory problems of the stress response system (Fries, Shirtcliff, & Pollak, 2008). This kind of lifestyle disruption is not unique to wildfires; all CRFs may in some way disrupt the normal processes of ECD.

"Pathway" explanations of associations between early life experiences and later life implications point to the persistent activation of the body's stress response through repeated exposures to stressors (Keating & Hertzman, 1999; Shonkoff et al., 2009). The pathways model accounts for stress throughout the life course, with each additional stressor reinforcing a deleterious effect, potentially sending a child into a cycle of maladaptive behaviour that exacerbates the overly activated stress response system. The pathways model argues that as stressors from different sources in a child's life are added together, a synergistic effect emerges, propelling them toward short-term consequences in education, criminality, drug use, and teen pregnancy. Hypothesized long-term consequences of a child's cumulative exposure include impacts on quality of working life, social support, chronic disease, and degenerative conditions (Keating & Hertzman, 1999).

The persistent activation of the body's stress response system that is characteristic of the pathways model may in some cases emerge as a consequence of climate change. The effects of

climate change are varied, but they may be persistent, as in the case of chronically polluted air. To illustrate the pathways model as caused by persistent environmental stress exposures, consider the CRF, ozone pollution. As discussed earlier, exposure to ozone pollution is associated with asthma diagnosis and exacerbation, and severe asthma is in turn associated with a host of developmental, emotional, and behavioural problems. This represents just one of many possible examples of persistent climate-relevant stressors. The stress tied to living through local harm caused by CRFs may be a major factor that sends children down pathways that compromise optimal well-being later in life.

While children are disproportionately affected by climate change because they are biologically more sensitive to their environments than adults (as noted above), and early experiences shape later outcomes, this disproportionate impact goes beyond biology alone. Today's children and youth both face a greater dose of climate change, and greater severity of climate change, by comparison with previous generations. The dose is larger, because children today face a greater number of expected years of climate change challenges by comparison with the aging population for whom climate change did not pose the same level of risk when they were young. The severity of the risk is greater, because rising carbon levels in the atmosphere contribute to increased frequency of extreme weather events, along with more dangerous levels of sea level rise, etc. This means that today's children are burdened with living through more severe risks of climate change than their parents and grandparents do, despite contributing far less to the causes of it. Regardless of the success or rate of reduction of greenhouse gas emissions, children born today will likely experience the effects of climate change, including sea level rise, well past 2100 (Masson-Delmotte et al., 2014). Climate change will therefore be a constant factor throughout their life course. This anticipated intergenerational inequity, along

with the physiological differences of youth, is one of the foundations of the disproportionate impact of climate change on children, and motivates this project to seek out databases about CRF that can inform future research about the influence of climate change may have on early child development in BC.

1.3.4 Early Development Instrument

The preceding sections discussed the relationship between climate change-relevant factors and child development generally. In this section, the Early Development Instrument (EDI) is discussed specifically, because it is the measure of child development that is the focus of this thesis project.

The Human Early Learning Partnership (HELP) launched EDI data collection in BC in 2001 in response to research showing that the experiences of a child in the early years of life strongly influence the child's life course trajectory. HELP's mission is to "create, promote, and apply new knowledge to help children and families thrive" (Human Early Learning Partnership, n.d.). The Early Development Instrument (EDI) contributes to this mission by systematically and regularly producing new information about the state of ECD in BC. The EDI evaluates the degree of successful acquisition of competencies within five core domains of development by the age of enrolment in kindergarten. The five domains are: physical health & well-being, social competence, emotional maturity, language & cognitive development, and communication skills & general knowledge.

For HELP, the school system was seen as an important opportunity for studying large numbers of children at once, with kindergarten being the first formal population-level gathering space for young children. By interacting on a nearly daily basis with students, kindergarten teachers are uniquely positioned to evaluate the development of the EDI's five domains in many

students at a time. Pre-determined cut-offs define vulnerability and suggest the potential for challenges in future schooling and society. The developmental status of children at the time of kindergarten is both an outcome of genetic makeup and early experiences, and a predictor of future school-based and societal outcomes (Keating & Hertzman, 1999).

The questionnaires are analyzed in temporal units termed *waves* which last two or three years each. As of 2021, there have been seven waves of the EDI collected, although the first wave is not typically analyzed for the sake of consistency, as the methodology was modified starting in wave 2. For some smaller neighbourhoods, annual participation is required to obtain enough data to accurately measure statistically significant changes. In urban neighbourhoods, there are enough children to warrant less frequent participation. Spatially, the EDI is measured at multiple levels: the entire province; five health authorities; 89 local health areas; 59 school districts; and 298 neighbourhoods. All levels of geographic focus lend themselves to future hypothesis-testing about the relationship between CRFs and child development in BC. The neighbourhoods vary in geographic area, depending on population size. That is, neighbourhoods that are less densely populated are represented by EDI boundaries that are spatially larger, and neighbourhoods that are more densely populated are represented by EDI boundaries that are spatially smaller. The EDI was designed to serve as a population-level measure; not an individual diagnostic tool. As a result, individual data are not typically reported. They are instead aggregated as a population-level measure, either as the proportion of children vulnerable in any given domain, or as the proportion vulnerable in one or more domains. These data give researchers, policymakers, and educators an understanding of the overall landscape of childhood development in BC, including its trends over time, from 2004 onwards.

1.4 Population Vulnerability and Adaptive Capacity to Climate Change

This section shifts the perspective from the experiences of individual children to the dynamics of populations. The reasons for this are twofold. First, the unit of analysis for the EDI itself is communities of children, aggregated together. Second, climate change is a phenomenon that is environmental, and therefore impacts groups of people sharing the same environmental conditions.

The aforementioned physical effects of climate change have the potency to disrupt entire communities, and their associated social determinants of health. Therefore, ongoing adaptive capacity of communities to withstand the harmful effects of climate change is critical. In the context of this project, BC communities that do not have sufficient adaptive capacity may be particularly vulnerable to the negative impacts of climate change, and this may put the important early stages of development for their resident children at risk. A terminology distinction should be made: *adaptation measures* refer to approaches to respond to the effects of climate change directly, such as building dikes to protect against sea level rise (Smith, J., Huq, & Klein, 2003). *Adaptive capacity* on the other hand is more general, and can be seen as the ability of a system to adapt. It is predicated on wealth and skills, technology and infrastructure, institutions, dissemination of information, power distribution, and social systems (Smith et al., 2003; Ajibade, 2012). Research suggests that the more consequential adaptations to climate change are related to adaptive capacity (Smith et al., 2003).

In the context of this project, consider the BC wildfire emergencies in 2017 and 2018. An adaptation relevant to wildfires may be the timely response of a well-trained and sufficiently staffed firefighter crew. Fighting the fire would minimize physical damage to communities and save large segments of forest from being lost. It serves as an essential response to the physical effect directly, but it does not represent a comprehensive ability of the province to adapt.

Adaptive capacity is a holistic characteristic. Optimal adaptive capacity could include the following elements and more: accurate and effective communication regarding fire risk and air quality for all communities; identification of high-risk buildings and available emergency training for individuals living or working in them; high-quality air filters installed in the majority of buildings; shelters for individuals experiencing homelessness to escape smoky air; income assistance for outdoor workers forced to stay home; and well-equipped emergency departments and pharmacies to respond to smoke-related health concerns. These elements of adaptive capacity would protect entire communities, including the children living in them.

1.5 Detailed Project Objective

This project sought to identify climate-relevant databases that could be used in concert with the EDI or other health and development data to test hypotheses about the relationship between (a) stressors associated with climate change such as wildfires and smoke, environmental event-related evacuations, floods, extreme heat, air pollution, and ground-level ozone and (b) aggregate (neighbourhood, community, or provincial) developmental vulnerability of young children (or other health and development outcomes) within British Columbia. While analyses within BC were of primary interest, databases that contained climate-relevant data across Canada were also examined to determine the degree to which they may facilitate examining BC by comparison with other provinces. For all potential hypotheses, analyses of CRF-EDI associations over time and over space were of interest.

1.6 Detailed Project Overview

First, this project considered four potential avenues of future research with respect to climate change and the EDI. Next, a list of generally accepted climate change indicators of interest was assembled. These were chosen based on an understanding of which indicators were

most likely to present themselves in BC. The complexity inherent in climate science makes the ascription of any given environmental event to the phenomenon of climate change difficult. The indicators of interest in this project were therefore termed "climate relevant factors" or CRFs.

Guided by existing literature, this project focused on the following CRFs: wildfires and their smoke, environmental event-related evacuations, floods, extreme heat, and ground-level ozone. Characteristics of interest for the CRFs were sought from each data source. These characteristics were: spatial resolution, temporal resolution, geographic coverage, and temporal coverage (range of dates). These characteristics were chosen because they describe how CRF data are collected and organized in time and space. They therefore inform which CRF-EDI associations are possible to analyze, and which CRF-ECD hypotheses are possible to investigate.

The four potential avenues of research on the relationship between climate change and the EDI that were considered in this project are organized in Table 1. They are also described below. With ECD in focus, each avenue includes associations between CRF exposures and proportions of vulnerability in children, as defined by the EDI.

First, the province of BC could be tracked over time on its aggregate CRF exposures and its aggregate EDI vulnerability outcomes. This would result in a display of the BC-specific CRF-EDI association over time.

Second, the same style of analysis could be conducted for any region or neighbourhood in BC; its unique CRF-EDI association could be assessed over time.

Third, the province of BC could be compared to other provinces at any point in time by plotting its aggregate CRF exposures against its aggregate EDI vulnerability outcomes, with each

province representing a discrete data point. This would result in a time-specific display of Canada's provincial CRF-EDI associations.

Finally, the same style of analysis could be conducted for individual EDI regions or neighbourhoods, creating a time-specific display of BC's more local-level CRF-EDI associations.

Together, the four research avenues described above informed the database search that was central to this project. Furthermore, these avenues informed the evaluation of each database's utility. This means that databases deemed promising were labelled as such based on their respective ability to facilitate the four research avenues of interest. Databases that were not deemed promising were less able or entirely unable to facilitate the four research avenues of interest.

Table 1. Potential avenues of future research on the CRF/EDI relationship, separated into different CRFs and into different levels of analysis.

	Potential Research Avenue – Level of Analysis			
Climate-relevant factor/EDI	**Temporal (neighbourhood kept constant)**		**Geographic (time kept constant)**	
Heat/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood
Wildfires/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood
Smoke/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood
Evacuations/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood
Ozone/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood
Flood/EDI	BC over time	EDI neighbourhood over time	BC to other provinces	EDI neighbourhood to EDI neighbourhood

Chapter 2: Methods

2.1 Scoping Review

Future investigations of the associations between CRFs and the ECD outcomes depend on available CRF data. In order to systematically and comprehensively ascertain which climate-relevant databases have been in use since the second wave of the EDI, a scoping review was conducted on *Covidence.org*. This review gathered publications from the *Web of Science* database that contained data on the climate-relevant factors chosen for this project. The search was limited to British Columbia and the years 2004 – 2020. As stated earlier, while the project's focus was on data collected within BC, identified databases that contained nationwide data were also considered for their potential utility in facilitating interprovincial analyses. A detailed description of the scoping review's search strategy is included in Appendix A.

The abstracts that emerged were reviewed for relevance, which was judged in light of the following eligibility criteria: that publications used data collected or modelled between 2004 and 2020, inclusively; that publications' data were collected or modelled in British Columbia; and that publications contained data relevant to heat, wildfires, smoke, evacuations, ozone, or floods. Publications that were advanced to the full-text review stage had their eligibility more closely examined. Publications that emerged from the review had their Digital Object Identifier (DOI), corresponding author name and email address, first author name, and publication date all stored in an electronic spreadsheet, along with the names and contact information for each climate-relevant database/data source itself. The databases that emerged from the review were then consolidated by grouping repeating databases together on a new spreadsheet.

2.2 Database Descriptive Information

To fully understand the climate-relevant data, descriptive information was required for each of the databases that emerged from the scoping review's publications. This information was

collected by sending emails to publication authors or key contacts at each database. In these emails, a brief project overview was provided, and the data characteristics of interest were requested. The data characteristics collected included spatial resolution, temporal resolution, spatial coverage (geographic area), and temporal coverage (range of dates available).

The data characteristics that were successfully gleaned from the email correspondence were organized in an electronic spreadsheet to keep track of all databases in a common place and common format. They were organized by CRF and by database name. This means that databases which collected data for multiple CRFs were listed separately; once in each CRF section.

2.3 Database Evaluation Criteria

In order to evaluate which databases would be most promising to study in conjunction with the EDI in future research, a set of ideal criteria were developed. Rather than establishing firm cut-offs which would qualify or disqualify databases dichotomously, the criteria were developed as guidelines that would make databases more or less promising on a continuum. These criteria are as follows:

- Spatial resolution – Higher is better.
- Temporal resolution – Higher is better, with diminishing returns at resolutions higher than daily.
- Geographic coverage – Higher coverage of Canada is better, but with focus placed on coverage of BC.
- Temporal coverage – Higher number of years – overlapping with BC EDI administration – is better.

This means that while there is no database that was perfect, an ideal database would be one that had a high level of spatial resolution (small scale cells), a high level of temporal resolution

(frequent data collection), a high level of geographic coverage (surveyed at least a large proportion of BC – if not all of Canada), and a high temporal coverage (contained data for as many years as possible within the range of 2004-2020).

These criteria represent qualities that may facilitate future research opportunities. In a broad sense, this is because they permit greater breadth in terms of the research questions that may be asked and answered. An explicit explanation of this is discussed below, and is presented for each criterion individually.

Spatial resolution determines the specificity of geographic analysis that is possible. This will be important because it will allow researchers to assign a given exposure variable to the same precise region as the outcome variable, as assessed by the EDI. With lower spatial resolution, aligning the CRF data with the same neighbourhood boundaries as the EDI may be more difficult, and may result in exposure misclassification. On the other hand, data that have a high degree of spatial resolution are of greater value because they would be more likely to allow CRF data to be divided along similar spatial boundaries as the EDI neighbourhoods. This would facilitate local-level analyses of the relationships between CRF exposures and ECD outcomes.

Temporal resolution of CRFs is important because it allows for the ascertainment of CRF outliers that represent extreme events. To illustrate this, consider the average temperature for a given neighbourhood over the course of a year. This may not be very meaningful in terms of assessing the impact of extreme heat on ECD because an intense but short heatwave is unlikely to skew the annual average temperature. However, data that have a high degree of temporal resolution (ie. hourly or daily measurements) will reveal major fluctuations in temperature, including heatwaves. These heat wave data will then be available to analyze in relation to ECD outcomes. This principle applies for all CRFs. Data with high temporal resolution afford future

researchers with more freedom in their analyses. Researchers could choose to focus on intense anomalies or long-term averages.

Geographic coverage is important because it determines the area that can be included in CRF-EDI analyses. With a small area of geographic coverage, the CRF-EDI relationship may still be possible to study, but in fewer EDI neighbourhoods. On the other hand, a database that collects data comprehensively across the entire province of BC or all of Canada may permit broader analysis. This may include more numerous EDI neighbourhoods, or even extend to province-level analyses. In other words, with sufficient geographic coverage, cross-sectional comparisons of different EDI neighbourhoods or different provinces can be conducted, assuming there are sufficient EDI data for those timepoints as well.

The final database evaluation criterion, temporal coverage, is important because it determines how extensive analyses may be over time. With data collected for only a short period of time within the years of EDI administration, CRF-EDI research would be limited, and would produce far less temporal information. Databases that have continuously collected data over long periods of time would be valued more because they would permit longitudinal analyses of the CRF-EDI relationship of a given region over long periods of time. Moreover, they would permit the cross-sectional comparison of the CRF-EDI relationship between different regions over longer periods of time.

For each CRF, the databases were evaluated on their degree of alignment with the aforementioned criteria. The criteria offer different pieces of information that are evaluated collectively to inform the potential utility of databases for future research inquiry. For instance, consider hypothetical high-quality data collected for an isolated study which was very short-term in length, or sporadic in terms of measurement patterns. These data would not be as useful for

future study on the relationship between a CRF and the EDI as a database with systematic, continuous data collection with routine intervals. This is because data that are collected continuously and consistently over long periods of time will more closely align with the longitudinal nature of EDI data collection. As another example, consider hypothetical data collected over a large range of years but for only a very small geographic region. These data would not be very useful for large-scale study of the CRF-EDI relationship in BC, but could be useful for a targeted study of a specific EDI neighbourhood. It was for this reason that the overall usability and research potential of the databases were taken into account and prioritized when evaluating the databases.

2.4 Database Categorization Criteria

In addition to these four evaluation criteria, the databases are also organized according to the following three data characteristics: the data represent either (a) direct measurement, (b) present or historical modelling data, or (c) future modelling data. Measured data are based on actual physical conditions, and are collected using instruments that acquire information about those physical conditions (e.g., Thermometers gain information about the temperature immediately surrounding them.). Modelled data do not collect information about actual conditions, but instead incorporate existing data, such as previous measurements or data trends, into algorithms in order to estimate the actual physical conditions in the past or present, or to predict the actual physical conditions in the future.

This classification is included because the type of data each database holds carries implications for any interpretations. First, the accuracy of measured data is its greatest strength. This is because it is based on actual physical conditions, and while there may be error inherent in all measurement techniques, additional error is always inherent in estimation or prediction.

However, most environmental exposure variables cannot be directly measured with continuity across an expansive geographic area. Instead, measurement must be conducted at discrete stations. On the contrary, modelled data are better equipped to estimate conditions across large geographic regions, but may be less accurate than measurements.

2.5 Ethical Considerations

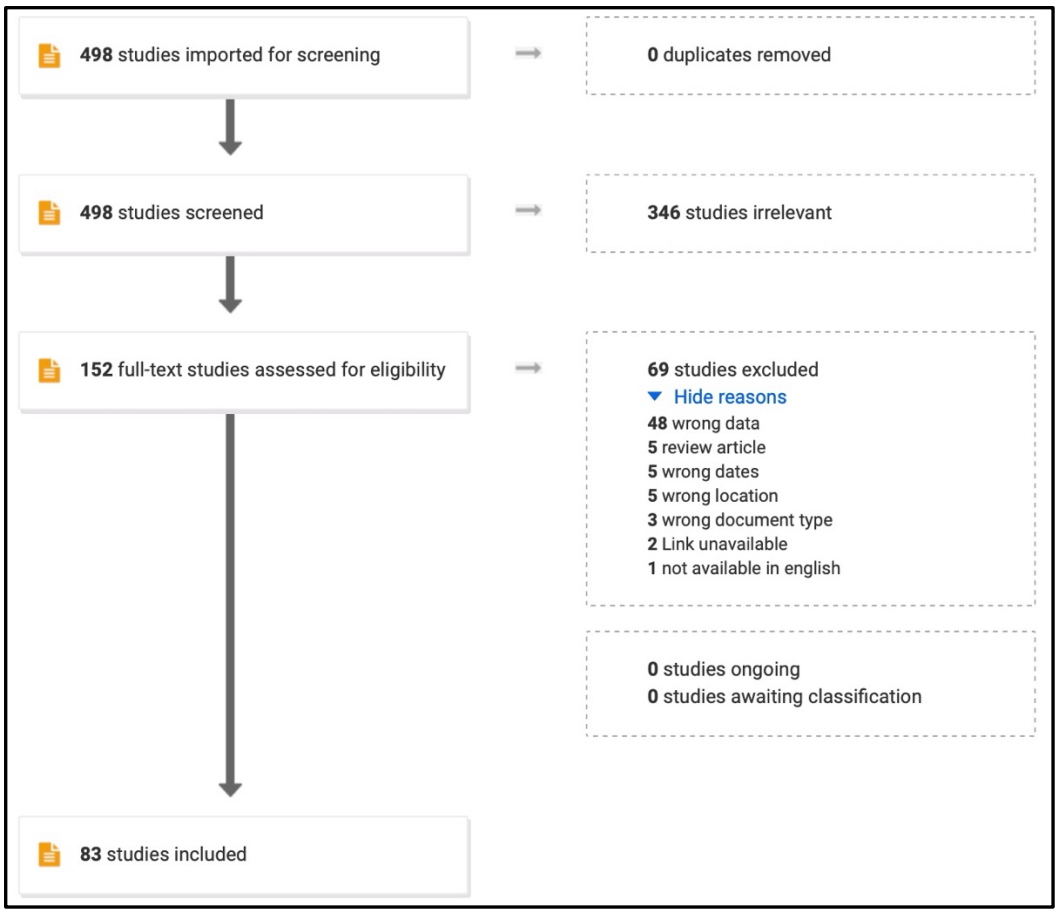
EDI data used in this study are publicly available and anonymized. Participation in EDI data collection is voluntary. Before the EDI is administered, parents and guardians of participating classes are provided with Informed Passive Consent Letters. These letters provide the opportunity for parents and guardians to withdraw their children from the study. Data collected by teachers are private and confidential, with individual student names removed upon completion of the questionnaire, and other personal information stored separately from teachers' answers in a secure environment. In the context of this specific thesis project, individual level data were not used. The EDI has been used by HELP to continuously collect data since 2001. Integrating these existing data with environmental stress exposure data will not create any additional ethical concerns beyond those inherent in the EDI, which have already been addressed by previous ethical reviews.

An ethics application was submitted in reference to the search for climate-relevant databases. This application was approved by the UBC Behavioural Research Ethics Board (H20-03876).

Chapter 3: Results

The scoping review's search resulted in 498 publications. Their abstracts were reviewed, and 152 studies were advanced to the full-text review stage. The latter resulted in the selection of 83 publications in light of the inclusion criteria described in the methods section and detailed in Appendix B. A full summary of the scoping review is provided in Figure 1. Following the review, 10 publications were subsequently excluded due to their failure to meet the eligibility criteria (1 for wrong data, 9 for wrong dates). As a result, this study examined 73 publications in search of databases that could be used for future research about the association between CRFs and EDI outcomes in BC.

Figure 1. Summary of scoping review (Covidence.org)



The databases were then consolidated by grouping repeating databases together. Twenty-nine separate databases were found from the scoping review. The subsequent correspondence with publication authors and database contacts led to the identification of two additional databases that were not identified in the scoping review's 73 articles. As a result, this project identified 31 CRF databases that could be used in future research about the association between CRFs and EDI outcomes in BC. These databases are presented in Table 2 below, along with the number of publications in which they were used and the CRF they measure and store.

After initiating correspondence with key contacts from each of the databases found from the scoping review, 18 responded. The data characteristics identified as a result of this correspondence were organized in an electronic spreadsheet and organized by CRF for each individual database. In some (but not all) cases in which responses from database contacts were not received, comprehensive information was available online to collect these data characteristics independently. Databases that collected data for multiple CRFs were listed separately; once in each CRF section.

The scoping review results, organized by CRF, are as follows: fourteen databases held temperature data, six held fire data, eight held particulate matter data, and four held ozone data. One held hydrometric data, which was not explicitly related to flooding, but was included due to its potential for ascertaining flooding events or flooding 'close calls'. No publications emerged from the scoping review that made use of evacuation data. With the addition of databases found outside of the scoping review, these figures become fifteen, six, nine, five, one, and one, respectively.

Table 2. Databases that emerged from scoping review, and number of publications that used their data. Databases that responded to correspondence are italicized and databases extraneous to the scoping review are listed in purple.

Database name	Number of uses	Climate-Relevant Factor
Environment and Climate Change Canada weather data	*20*	*Temperature*
BC Ministry of Environment and Climate Change Air Quality Monitoring	*16*	*Ozone, Particulate Matter, Temperature*
British Columbia Centre for Disease Control (BCCDC) Optimized Statistical Smoke Exposure Model (OSSEM)	*5*	*Particulate Matter*
ClimateNA	*5*	*Temperature*
Metro Vancouver Air Quality	*5*	*Ozone, Particulate Matter, Temperature*
NASA – Moderate Resolution Imaging Spectroradiometer (MODIS) – Fire	4	Fire
ClimateBC	*3*	*Temperature*
NASA – Moderate Resolution Imaging Spectroradiometer (MODIS) – PM2.5	3	Particulate Matter
Heat Vulnerability Index (Raster-based model and vector-based model, combining census data and thermal satellite imagery)	2	Temperature
NASA – Moderate Resolution Imaging Spectroradiometer (MODIS) – Temperature	*1*	*Temperature*
NASA's Total Ozone Mapping Spectrometer (TOMS) dataset	2	Ozone
Bluesky (BS): The western Canada wildfire smoke forecasting framework	1	Particulate Matter
Canadian National Fire Database (NFDB)	*1*	*Fire*
Carrot Lake Experimental Burn Project	*1*	*Fire*
CubeSat data provided by Planet	1	Fire
Dokie Wind Energy Project	*1*	*Temperature*
FireWork Smoke Forecasting System	*1*	*Particulate Matter*
Global SPEI database (Weatherbase.com)	*1*	*Temperature*
Mobile monitoring to measure residential wood smoke	*1*	*Particulate Matter*
MODIS – Ozone	1	Ozone

Multivariate Adaptive Constructed Analogs (MACA) datasets	*1*	*Temperature*
NASA Global Fire Weather Database (GFWED)	*1*	*Temperature*
Natural Disturbance Database – Aerial Overview Survey	*1*	*Fire, Flood*
Pacific Agri-Food Research Centre, Summerland	1	Temperature
Pacific Climate Impacts Consortium's (PCIC) BC Station Data tool (AKA: Provincial Climate Data Set from Climate Related Monitoring Program)	*1*	*Temperature*
Sentinel-1 Synthetic Aperture Radar (SAR) C-band time series data (European Space Agency's First Copernicus Mission)	*1*	*Fire*
Statistical model to predict the smoke height observed by CALIPSO	1	Particulate Matter
TerraClimate	*1*	*Temperature*
National Water Data Archive	*1*	*Flood*
CANUE	0	Ozone, Particulate Matter, Temperature
NRCan	0	Evacuations

Chapter 4: Discussion

In this section, the results of the scoping review are interpreted in order to determine what may be the most promising data resources for future research on the relationship between climate change and ECD – or other health and development outcomes – in BC. After briefly revisiting the database evaluation criteria, a description of the most promising databases that emerged from the scoping review is presented. Finally, each CRF subsection concludes with various specific promising lines of inquiry that may be open to explore based on these databases.

4.1 Database Evaluation & Categorization Criteria

As discussed in the methods section, the available databases were categorized as directly measured data, historical modeled data, and future modeled data. The databases were also examined in light of their spatial resolution, temporal resolution, geographic coverage, and temporal coverage in order to identify the most promising data resources to guide future hypothesis-generation for research about the relationship between CRFs and ECD or other health and development outcomes in BC. Research opportunities specific to the EDI were then expanded upon in more detail, based on select databases for each CRF. The research opportunities discussed do not represent an exhaustive list of every research possibility. Rather, this section offers a sampling of some of the questions that intuitively follow from the database strengths for each CRF.

4.2 Promising Databases and Research Opportunities

Each of the CRF databases that emerged from this project's scoping review were assessed based on the degree to which they fit the aforementioned criteria. The databases that were found to be promising for each CRF are presented in Table 3. Finally, the promising

databases below are compared and contrasted in order to provide a deeper analysis of which databases may be strongest for studying associations with the EDI.

Table 3. Databases deemed promising and their data type(s). A=measurement; B=historical or present modelling; C=future modelling

Database Name	Data Type
BC Ministry of Environment and Climate Change Air Quality Monitoring	A
Canadian National Fire Database (NFDB)	A
Environment and Climate Change Canada weather data	A
Metro Vancouver Air Quality	A
NASA's Total Ozone Mapping Spectrometer (TOMS) dataset	A
National Water Data Archive	A
NRCan	A
Pacific Climate Impacts Consortium's (PCIC) BC Station Data tool (AKA: Provincial Climate Data Set from Climate Related Monitoring Program)	A
British Columbia Centre for Disease Control (BCCDC) Optimized Statistical Smoke Exposure Model (OSSEM)	B
CANUE	B
Natural Disturbance Database – Aerial Overview Survey	B
ClimateBC	B, C
ClimateNA	B, C
FireWork Smoke Forecasting System	C

4.2.1 Heat/Temperature

Description of promising databases

The study identified 15 heat/temperature databases. Six were found to be promising based on the four criteria prioritized in the methods discussion.

First, the Pacific Climate Impacts Consortium's (PCIC) *BC Station Data Tool* is promising in part because its spatial resolution is high; the database holds temperature measurement information from 7044 stations that have operated across BC. The number of stations that have data between 2004 and 2020 is 1913. Measurement frequency (i.e., temporal resolution) varies from station to station, but is often hourly or daily. The geographic coverage extends across BC. The database's temporal coverage varies from station to station as well, but date ranges for each station are available.

Second, Environment and Climate Change Canada's (ECCC) weather data have been measured and collected from 1772 BC stations over time. 1395 are operational in BC as of 2021. Depending on individual climate observing programs and climate elements, weather observations at a climate station are recorded at three basic intervals: hourly, daily, or monthly. The geographic coverage of this database is all of Canada. Finally, the temporal coverage varies from station to station as well.

Third and fourth, the BC Ministry of Environment and Climate Change operates air quality monitoring stations in conjunction with Metro Vancouver Air Quality. In addition to measuring pollutant levels, they also measure air temperature from 277 operational monitoring stations throughout BC. These stations collect measurements on an hourly basis, and the range of dates for which data are available is from 1982 to the present day.

Fifth, ClimateNA is an application that uses published climate normal data (Daly et al., 2008) to model historical and future temperature. It allows users to obtain scale-free modelled climate data at any resolution. Its temporal resolutions are monthly, seasonal, and annual. The application covers all of North America, and it can generate data from 1901 to 2100.

The sixth and final promising database for the heat/temperature CRF is the Canadian Urban Environmental Health Research Consortium (CANUE). CANUE is an organization that collects, organizes, and standardizes exposure data across Canada that are relevant to environmental health. CANUE holds a wide range of data for different indicators of heat/temperature, calculated using historical climate modelling software, and are distributed to researchers across Canada. It contains data at the spatial resolution of Canadian postal codes, and daily temporal resolution. It covers all of Canada, and has data from 1985 to 2015.

Relative strengths of promising databases

The PCIC database and the ECCC have comparable temporal resolution, and both are collected across the province of BC. The PCIC has more available stations between 2004 and 2020 than the number of ECCC stations in operation presently, which may contribute to a slightly higher spatial resolution. This spatial resolution may facilitate the analysis of temperature in relation to EDI boundaries. On the other hand, ECCC stores data across Canada as opposed to BC alone, and this may facilitate interprovincial analyses. Common to both of these databases is their data collection from station measurements. While these produce accurate local exposure data, extrapolation of measurements to other regions introduces error. This is a problem because stations are not evenly distributed across the province, and this leaves some regions with less accurate exposure data. For instance, if a region is assigned an exposure value from a nearby station and that value does not accurately represent the region of interest, exposure misclassification occurs.

The collaboration between the BC Ministry of Environment and Climate Change and Metro Vancouver Air Quality has a lower spatial resolution compared to the PCIC and ECCC,

and this is due to a lower number of stations. Nevertheless, CRF-EDI research questions that investigate heat or temperature influences on ECD would be able to focus on extreme heat anomalies like heatwaves because of the high temporal resolution data available from ECCC. With high temporal coverage and comprehensive geographic coverage (all of Canada), research potential is quite broad. For instance, researchers could investigate the relationship between the number of heatwave exposures in any neighbourhood, or in the province as a whole, and childhood vulnerability outcomes over time. Furthermore, researchers could compare the heatwave-EDI associations between different provinces or EDI neighbourhoods at any point in time, in terms of the magnitude of their respective associations between heatwaves and EDI vulnerability.

ClimateNA's strong geographic and temporal coverage and high spatial resolution lends itself to various types of research questions including interprovincial and EDI neighbourhood studies over long periods of time. However, its monthly temporal resolution precludes the detection and analysis of extreme fluctuations that occur on an hourly or daily scale. Research into the impact of short-term heat events on ECD would require higher temporal resolution. Short-term independent variables could include heatwaves or the number of days per year above a certain temperature percentile for a given region. These dependent variables would not be possible to study using ClimateNA. However, monthly temperature averages may be useful for certain types of research questions, such as the impact of warmer weather trends (i.e., warmer months) on ECD. Independent variables may include the number of months per year above a certain temperature percentile for a given region.

CANUE's geographic coverage and temporal resolution (daily) are its benefits. Furthermore, its postal code spatial resolution aligns well with how EDI boundaries are constructed. The temporal coverage of data that are available as of this writing is from 1985 to 2015, but there are plans to update CANUE data, according to a CANUE director. As it stands now, this already covers the majority of time since the EDI was initiated in BC, but excludes the last six years. Until the data are updated, this would preclude analyses related to heat/temperature in recent years.

4.2.2 Wildfires

Description of promising databases

The study found identified six fire databases. Of these, two were found promising based on the criteria.

First, the Canadian National Fire Database, run by Natural Resources Canada (NRCan), collects satellite hotspot measurement data (thermal detection of fire locations) at highly specific latitude and longitude coordinates and has collected data daily across Canada since 1998.

Second, the Natural Disturbance Database, under the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development conducts Aerial Overview Surveys of forest health. The severity of forest damage is sketched onto customized maps by trained observers in planes, and this introduces potential for subjectivity and inconsistency in the spatial resolution and accuracy. The surveys have been conducted annually from 1999 to the present day. These surveys are only conducted for forested areas of BC.

Relative strengths of promising databases

The Canadian National Fire Database has a high degree of alignment with the four criteria, making it a very promising database to use in order to study the association between wildfires and ECD. Researchers could explore the relationship between wildfire exposures and ECD outcomes in a given neighbourhood or in the province as a whole, over time. Furthermore, they could conduct interprovincial or inter-neighbourhood comparisons for any EDI year, detailing how the relationship between wildfires and EDI outcomes varies across provinces and neighbourhoods.

The Natural Disturbance Database is less promising. While it contains data for the entire range of dates since the EDI was initiated in BC, it covers no other provinces than BC, and only collects data annually. This temporal resolution is substantially lower than that of the Canadian National Fire Database, making the Natural Disturbance Database insufficiently equipped to study the short-term dynamics of wildfires as they progress each year. Moreover, the subjective nature of the data collection makes consistent spatial resolution unlikely.

4.2.3 Smoke/Particulate Matter

Description of promising databases

The study identified nine particulate matter databases. Of these, six were especially promising. First, Canada's wildfire smoke prediction system called Firework produces smoke ($PM_{2.5}$) forecasts at the spatial resolution of 10 kilometres every 12 hours from early April to late October. It covers all of Canada and has been in operation from 2013 to the present day.

Second and third, the Optimized Statistical Smoke Exposure Model (OSSEM) has two versions that both produce present-day smoke ($PM_{2.5}$) estimates at a spatial resolution of 5 km^2. They produce these estimates every 24 hours (OSSEM-24hr) and every 1 hour (OSSEM-1hr) respectively. These cover all populated areas of BC from April to September. OSSEM-24hr has operated from 2003 to the present day, whereas OSSEM-1hr has operated from 2010 to 2015.

Fourth, CANUE holds $PM_{2.5}$ modelled estimates that are organized by postal codes, collected monthly for all of Canada, from 2000-2016.

Fifth and sixth, the BC Ministry of Environment and Climate Change operates 277 air quality monitoring stations in conjunction with Metro Vancouver Air Quality, as discussed in section 4.2.1. These stations, located throughout BC, collect measurements on an hourly basis, and the range of dates for which data are available is from 1982 to the present day.

Relative strengths of promising databases

The Firework and CANUE databases both span all of Canada for a number of years. This facilitates analysis of the temporal trend in the relationship between BC's aggregate particulate matter exposure and EDI vulnerability outcomes, as well as comparisons between provinces in terms of their respective particulate matter-vulnerability associations. In addition, the Firework database permits analysis of short-term particulate matter increases.

In spite of those strengths, Firework and CANUE both have disadvantages. The disadvantage of Firework is its low spatial resolution, as well as the fact that it is a forecasting system. Its low spatial resolution makes it ill-suited for studying individual neighbourhoods, and its forecasting characteristics introduces error to its accuracy.

The disadvantage of CANUE is its low temporal resolution, which would prevent analysis of these short-term particulate matter spikes. In terms of conducting long-term analyses on individual neighbourhoods, CANUE would be better suited. These analyses would include calculating individual neighbourhood trends in the particulate matter-vulnerability relationship over time, as well as cross-sectionally comparing neighbourhoods during any year on their respective particulate matter-vulnerability associations.

A higher spatial and temporal resolution exists within the OSSEM databases, but only for BC. OSSEM-24hr is particularly promising due to its longer temporal coverage relative to OSSEM-1hr. While OSSEM-24hr has a slightly lower temporal resolution than Firework, it is still able to detect particulate matter spikes, and it strongly outperforms Firework on temporal coverage and spatial resolution. This means OSSEM-24 would be well-suited for investigation into longer-term analyses on particulate matter spikes. Although OSSEM has a higher spatial resolution than Firework, $5km^2$ likely remains too large to perfectly pair with local EDI neighbourhoods, so analysis of the particulate matter-ECD relationship at a local level may only be possible in some neighbourhoods – if any. Finally, OSSEM would be well-suited to studying the relationship BC's aggregate particulate matter exposure and its ECD outcomes over time.

Overall, each of the particulate matter databases identified in this section have relative strengths and weaknesses in light of the project's criteria for pairing CRF data with the EDI data. It should be stressed again that the criteria represent an attempt at characterizing the properties of the ideal database, which could answer a range of questions singlehandedly. However, a single database's weakness on any criterion does not necessarily preclude its utility to study CRF-ECD relationships. In the case of particulate matter, the relative strengths and weaknesses of the four

databases listed may suggest the opportunity for different databases to answer different questions.

4.2.4 Evacuations

Description of promising databases

The study identified one evacuation database. The database is run by Natural Resources Canada (NRCan), and is called the Wildland Fire Evacuation Database. Its spatial resolution is high, as the locations of the fires and evacuations are collected using highly specific latitude and longitude coordinates. For the CRF of evacuations, a high degree of temporal resolution is not as critical as other CRFs because the rate of change in evacuation numbers is not likely to change faster than daily, unlike other CRFs such as temperature or smoke/particulate matter. In the case of the NRCan database discussed here, the date on which the evacuation is issued and the date on which the evacuation is closed were both listed in most (but not all) cases. This represents a temporal resolution on the scale of days as opposed to hours or months. The database's geographic coverage was the entirety of Canada, and its temporal coverage was from 1980 to the present day.

Relative strengths of promising databases

The geographic and temporal coverage of this database, as well as its highly specific geographic coordinates are three of its major strengths. In addition to these characteristics, additional descriptive information is stored. Some of this information includes the evacuation cause (eg. threat, transportation/access, smoke/health), the type of community that was affected, the type of people that were affected (eg. campers, residents, students, vulnerable members of the

population), and the number of evacuees. One of the weaknesses of the database is its singular focus on fires. This therefore excludes evacuations with other causes, such as floods.

These data characteristics suggest a range of possible research questions, which may include investigating the relationship between evacuations and ECD outcomes over time for neighbourhoods, and for BC as a whole as well. Furthermore, using NRCan data facilitates investigation into how the evacuation-vulnerability associations differ from province to province and from neighbourhood to neighbourhood.

4.2.5 Ozone

Description of promising databases

The study identified four promising ozone databases. The first is the BC Ministry of Environment and Climate Change Air Quality Monitoring, and this works in concert with the second, which is Metro Vancouver Air Quality. Together, they collect hourly measurements (ppb) across the province at 277 monitoring stations. These have been operated from 1982 to the present day.

Third, CANUE holds ozone (ppb) model estimates at the spatial resolution of Canadian postal code boundaries with eight-hour averages. These data cover all of Canada from 2002-2015.

Finally, the National Aeronautics and Space Administration (NASA) operates the Total Ozone Mass Spectrometer (TOMS) which collected data in Dobson units (DU) between 50 and 200 kilometres wide. These measurements take place daily across the globe and have been collected from 1996 to the present day.

Relative strengths of promising databases

The BC Ministry of Environment and Climate Change and its partner Metro Vancouver Air Quality share generally strong alignment with all of this study's criteria. While future researchers may find the number of stations insufficient to study the province of BC comprehensively, they may be able to study ozone-ECD relationships in select locations. Neighbourhoods with these measurements could be compared with each other cross-sectionally, and those select neighbourhoods could be studied over time to track the relationship between high ozone events and ECD.

CANUE is similar to the Ministry of Environment and Metro Vancouver databases, but has the added strength of spatial resolution on the level of postal code boundaries. However, CANUE's eight-hour averages are less able to detect short-term fluctuations compared with the Ministry of Environment's hourly measurements. For the years that CANUE data are available, the full scope of research questions discussed in prior sections are possible. These include investigations into the relationship between ozone exposure and ECD outcomes over time for individual EDI neighbourhoods as well as for BC collectively. Moreover, CANUE data would allow cross-sectional analyses, comparing different neighbourhoods to each other, as well as comparing BC to other provinces.

The NASA TOMS database has consistent and longstanding data collection. However, it falls short by comparison with the other data sources on both spatial resolution and temporal resolution.

4.2.6 Floods

Description of promising databases

Two promising flooding-relevant databases were found from the scoping review. The first is called the National Water Data Archive and is managed by Environment and Climate Change Canada. It has daily, monthly, and annual measurements of rivers, streams, and lakes in stations across all of Canada, and contains data spanning from 1850 to 2009. While data explicitly describing flooding events are not available, it does store hydrometric data including daily and monthly means of flow and water levels, and in some locations stores peaks and extremes. The degree of alignment between these water measurements and this project's criteria make it a promising source of information for future study. For example, if researchers calculate flooding events or flooding 'close calls' using the National Water Data Archive, it creates the opportunity for research inquiry into the trajectory of the relationship between flood exposures and ECD over time, both for individual neighbourhoods and for BC as a whole. It would also allow cross-sectional analyses, both to compare provinces to each and to compare neighbourhoods to each other.

The second database is the Natural Disturbance Database, which was discussed earlier in regard to fire data. This database includes flooding data as it pertains to forest health. The severity of forest damage is sketched onto customized maps by trained observers in planes. These overview surveys are conducted annually across forested areas of BC from 1999 to the present day. The spatial resolution may be influenced by human error.

Relative strengths of promising databases

The Natural Disturbance Database is less promising for future EDI research. Its temporal range is sufficiently comprehensive to align with EDI collection years in BC, but it only covers forests (not urban areas) and is only conducted in BC. Moreover, data are only collected annually. This temporal resolution is not ideal for studying the short-term dynamics of flooding events each year. Finally, the nature of the data collection introduces data quality risks related to observer error.

4.3 Summary of Avenues for Future Research

As discussed throughout, this project was motivated by the opportunity to use EDI data as outcomes of interest in research on the phenomenon of climate change in BC, and wherever possible, throughout Canada. The methods section identified four potential avenues of future research (summarized in Table 1:

1. The province of BC could be tracked over time.
2. Any individual EDI neighbourhood could be tracked over time.
3. The province of BC could be compared to other provinces at any point in time.
4. Any individual EDI neighbourhood could be compared to other neighhourhoods at a single point in time.

Table 4 identifies which of the promising CRF databases identified by this study may be able to serve each of the four avenues of potential future research on the relationship between CRF exposures and EDI outcomes. However, careful consideration is urged when interpreting the contents of Table 4, for two reasons.

First, the evaluation of the databases identified in this project was strictly based on their utility in facilitating research on EDI outcomes. Therefore, if a database was not identified as promising or likely to serve any of the research avenues in focus, this does not reflect an overall weakness in the database or a lack of utility. As discussed in section 1.1, the evaluation of the databases is intended to provide a useful summary, specifically for EDI researchers, to utilize moving forward. Nevertheless, it may serve other research objectives as well, and the summary of useful databases should be interpreted with that context in mind.

The second reason for careful consideration of Table 4 is related to the variety of future research objectives that may take advantage of the present database summary. The purpose of Table 4 is to offer an accessible and general summary of where the databases align with the potential research avenues. However, successful alignment ultimately depends on the specific hypotheses that future research projects aim to test, and would need to be evaluated on a case-by-case basis in light of each prioritized hypothesis. The current project is not designed to suggest how to use the EDI or any other health or development outcome data in these research avenues, as experts in each field are best suited to make those decisions at their own discretion. It is however designed to make hypothesis generation and data resource selection simpler. This intention motivates the presentation of a more general summary of databases that align with the four research avenues.

Table 4. Summary of databases fitting the four avenues of potential research

	Potential Research Avenue			
Climate-relevant factor/EDI	**BC over time**	**EDI neighbourhood over time**	**BC to other provinces**	**EDI neighbourhood to EDI neighbourhood**
Heat/EDI	CANUE, ClimateNA, PCIC, ECCC	CANUE, ClimateNA, PCIC, ECCC	CANUE, ClimateNA, ECCC	CANUE, ClimateNA, PCIC, ECCC
Wildfire/EDI	The Canadian National Fire Database	The Canadian National Fire Database	The Canadian National Fire Database	The Canadian National Fire Database
Smoke/EDI	CANUE, Ministry of Environment, Metro Vancouver Air Quality, OSSEM-1hr, OSSEM-24hr, Firework	CANUE, Ministry of Environment, Metro Vancouver Air Quality, OSSEM-1hr, OSSEM-24hr, Firework	CANUE, Firework	CANUE, Ministry of Environment, Metro Vancouver Air Quality, OSSEM-1hr, OSSEM-24hr, Firework
Evacuation/EDI	NRCan: Wildland Fire Evacuation Database	NRCan: Wildland Fire Evacuation Database	NRCan: Wildland Fire Evacuation Database	NRCan: Wildland Fire Evacuation Database
Ozone/EDI	BC Ministry of Environment, Metro Vancouver Air Quality, CANUE	BC Ministry of Environment, Metro Vancouver Air Quality, CANUE	CANUE	BC Ministry of Environment, Metro Vancouver Air Quality, CANUE
Flood/EDI	National Water Data Archive	National Water Data Archive	National Water Data Archive	National Water Data Archive

Table 4 provided a comprehensive summary of the databases that generally align with the research avenues discussed in this project. However, this does not provide an example of the specific research opportunities that stand out among them as perhaps the most natural places to

begin the CRF-EDI research process. Below, two specific opportunities are presented. These are by no means exhaustive, but they do represent intuitive lines of questioning that flow naturally from the environmental exposures common to BC and the data resources identified in this project.

The first of these opportunities is to explore the connection between evacuations due to wildfires and ECD outcomes. Wildfire events have become commonplace in British Columbia, causing regular and extensive damage. Using the Wildland Fire Evacuation Database, researchers could investigate the region-specific evacuation-EDI associations as temporal trends to determine whether individual communities experiencing certain years of heavy evacuation incidence suffered worse ECD vulnerability outcomes as well. Due to the stress, uncertainty, and fear that evacuations can impose upon people, it is worth investigating whether these individual years have implications for ECD in certain communities.

The second research opportunity to highlight is exploring the relationship between particulate matter exposure and ECD outcomes, focusing on particularly bad wildfire years, and comparing different regions in that year. Using the OSSEM-24h model as the data source, researchers could determine the year-specific PM-EDI associations in regions across the province to determine whether communities that lived with high amounts of smoke exposure for days or weeks on end suffered worse in terms of ECD outcomes than other areas that experienced a lesser degree of smoke exposure.

4.4 Interpretations of Future Research

Using the EDI as an example, the research initiatives that this project facilitates will represent an important step toward understanding the relationship between climate change and

the developmental milestones of children in BC. Nevertheless, caution will need to be exercised in interpreting the results of future research. In section 4.3, the utility of each promising database was explored, and the potential outcomes of future research were indicated. However, it is critically important to refrain from oversimplifying the CRF-EDI relationship. Just as climate change is an incredibly complex phenomenon with a wide range of manifestations that impact populations differently, ECD is a similarly complex process that is impacted by a wide range of factors.

For example, if climate change manifests in a substantial increase in the incidence of heatwaves, and this corresponds with an increase in childhood vulnerability, this does not necessarily mean climate change has directly caused this uptick in vulnerability. Instead, it may be entirely possible that children attending preschool and kindergarten spend much of their time indoors, protected from the punishing heat. However, for parents working physical outdoor jobs, this recurring pattern of heatwaves may become a deep burden. Despite the best of intentions to be loving and attentive, a parent forced to do physical work through repeated heatwaves could find it much harder to exhibit the tender, compassionate closeness a child needs during its early years, with consequences for that child's development. In fact, this pattern may play out more noticeably in communities where a large proportion of adults work outdoors.

This example is intended to represent the complexity inherent in interpreting the future results of CRF-ECD research. The outcomes of the research that this project facilitates will be helpful in understanding climate change's impact on ECD in BC, but only if appropriate steps are taken to collect relevant contextual covariates and incorporate them into analyses. Even in the absence of such statistical prudence, general caution of interpretations is strongly encouraged

in order to identify a sufficiently holistic understanding of the entire context surrounding CRFs and ECD.

Chapter 5: Conclusion

5.1 Project Summary

The objective of this project was to explore what databases are available to use in conjunction with the EDI or other health and development data to facilitate future research on the relationship between climate change and ECD or health and development outcomes. To do so, a scoping review was conducted to collect publications containing 6 CRFs. These CRFs are: heat/temperature, wildfires, smoke/particulate matter, evacuations, ozone, and floods. The scoping review resulted in 73 full-text publications. These publications facilitated the identification of 29 databases. Correspondence with publication authors and database contacts resulted in the inclusion of 2 additional databases, meaning 31 databases were ultimately included. This correspondence with authors and other contacts also produced information about spatial and temporal coverage as well as spatial and temporal resolution for each database. The characteristics of the 31 databases were evaluated for their potential utility for future analysis in conjunction with the EDI.

Of the 31 databases included in this project, ten were ultimately considered promising. 'Promising' refers to the opportunity each database creates to meaningfully advance the academic research that is already being conducted on ECD in BC, especially as it relates to climate change and CRFs. These databases are each briefly described below.

For studying ECD in conjunction with heat/temperature, ECCC's temperature data are promising because they are collected from a large number of stations across the country, and have a degree of temporal coverage and temporal resolution. For studying ECD in conjunction with wildfires, the Canadian National Fire Database has a high degree of alignment, showing where fires in Canada have been located on a daily basis since before the EDI was first

administered in BC. For studying smoke or particulate matter as it related to ECD, there is not one single database that is the most promising – it depends on the type of research question being asked. However, CANUE, Firework, and BCCDC's OSSEM databases could all be used to answer questions about the particulate matter-ECD connection. One database stood out as promising for studying evacuations. This was the NRCan database, which has tracked wildfire-related evacuations across Canada for many years, and with exceptional detail. For studying ozone with ECD, the most promising databases are the Ministry of Environment weather stations (which collaborates with Metro Vancouver), and CANUE. These both have data of high temporal resolution for a large number of years. The final CRF addressed in this project was flooding. The most promising database found for flooding was the National Water Data Archive. This archive contains hydrometric data relating to flow and water levels. While it meets all of database evaluation criteria laid out in this project, it does not explicitly identify flooding events. The utility of this database in studying the flooding-ECD relationship will hinge on researchers' ability to ascertain flooding events or flooding 'close calls' using these data.

5.2 Future Directions

This project is primarily intended to facilitate future research endeavours focused on ECD, as assessed by the EDI. As discussed throughout, while the specific data characteristics sought for this project were motivated by potential alignment with the EDI, they may nevertheless provide valuable information for other lines of academic inquiry. First, this project may provide useful background information for HELP's other development indices and projects: the Toddler Development Instrument, the Childhood Experiences Questionnaire, and the Middle Development Instrument. Second, it may facilitate inquiry that is more directly focused on monitoring climate change in BC and its association with other public health issues beyond child

development. Regardless of how the results of this project are utilized, the identification, description, and summary of useful climate-relevant databases remains the focus of this work, with the central motivation of aiding future research.

5.3 Project Implications

When it comes to taking action on climate change, the rate of emissions reductions is a critically important factor in controlling the extent of global warming and its associated impacts. However, due to their age, children born today into democratic societies are virtually powerless to influence these political-environmental decisions that would mitigate climate change and protect their futures. This is called voting asymmetry (Boston & Lempp, 2011). Voting asymmetry is inauspicious for the life courses of today's children because there is evidence that voters tend to focus primarily on short-term, local issues (Boston & Lempp, 2011). Research also suggests that people have a tendency to underestimate future benefits and overestimate present costs, and to overvalue present benefits and undervalue future benefits (Boston & Lempp, 2011). Together, these tendencies conflict starkly with the political will that is necessary to adequately confront the climate crisis. That is, effective climate action requires short-term costs for future benefits. Its effects will be manifest globally, and on the temporal scale of decades and centuries, rather than relatively short-term election cycles. In the case of BC, the election cycles last four years or less. Striving to understand intergenerational inequity – including voting asymmetry and the general tendencies of political discourse that delay sufficient climate action – may be an important step in the process of reframing climate action as a worthy short-term priority.

The EDI was designed in part to promote evidence-informed policy and program decisions, and with appropriately focused research, it may be useful to motivate future climate policy adaptations. As more waves of HELP's EDI are collected in BC, it may be possible to

gather systematic insight on the climate change-ECD relationship, and wield this insight to motivate an appropriate degree of urgency on the part of policymakers. Disseminating this information to politicians and the electorate alike may break through some of the aforementioned barriers of voting priorities – namely the tendency to focus on short-term, local issues. This is because climate change-ECD studies have potential to put the global emergency of climate change in perspective as a local issue, and saliently display the trajectory of its effects over time.

References

Ajibade, I. (2012). *Climate security and vulnerable populations in Canada: Making a case for ambitious policies*

Basu, R. (2009). High ambient temperature and mortality: A review of epidemiologic studies from 2001 to 2008. *Environmental Health, 8*(40)

Basu, R., & Ostro, B. (2008). A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *American Journal of Epidemiology, 168*(6), 632-637.

BC Wildfire Service. (2020). *Wildfire season summary - province of British Columbia.* Retrieved Nov 21, 2020, from https://www2.gov.bc.ca/gov/content/safety/wildfire-status/about-bcws/wildfire-history/wildfire-season-summary

Beverly, J., & Bothwell, P. (2011). Wildfire evacuations in Canada 1980–2007. *Natural Hazards (Dordrecht), 59*(1), 571-596. doi:10.1007/s11069-011-9777-9

Blackman, J., & Gurka, M. (2007). Developmental and behavioral comorbidities of asthma in children. *Journal of Developmental & Behavioral Pediatrics, 28*(2), 92-99. doi:10.1097/01.DBP.0000267557.80834.e5

Bobb, J. F., Obermeyer, Z., Wang, Y., & Dominici, F. (2014). Cause-specific risk of hospital admission related to extreme heat in older adults. *JAMA : The Journal of the American Medical Association, 312*(24), 2659-2667. doi:10.1001/jama.2014.15715

Boston, J., & Lempp, F. (2011). Climate change. *Accounting, Auditing & Accountability Journal, 24*(8), 1000-1021. doi:10.1108/09513571111184733

Braveman Paula, & Barclay Colleen. (2009). *Health disparities beginning in childhood: A life-course perspective* American Academy of Pediatrics.

Buttle, J. M., Allen, D. M., Caissie, D., Davison, B., Hayashi, M., Peters, D. L., et al. (2016). Flood processes in Canada: Regional and special aspects. *Canadian Water Resources Journal, 41*(1-2), 7-30. doi:10.1080/07011784.2015.1131629

Campbell, E. E., Gilliland, J., Dworatzek, P. D. N., Vrijer, B. D., Penava, D., & Seabrook, J. A. (2018). Socioeconomic status and adverse birth outcomes: A population-based Canadian sample. *Journal of Biosocial Science, 50*(1), 102-113. doi:10.1017/S0021932017000062

Chen, T., Kuschner, W. G., Gokhale, J., & Shofer, S. (2007). Outdoor air pollution: Ozone health effects. *The American Journal of the Medical Sciences, 333*(4), 244-248. doi:10.1097/MAJ.0b013e31803b8e8c

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., et al. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology, 28*(15), 2031-2064. doi:10.1002/joc.1688

Duncan, R., Duncan, G., Stanley, L., Aguilar, E., & Halfon, N. (2020). The kindergarten early development instrument predicts third grade academic proficiency. *Early Childhood Research Quarterly, 53*, 287-300. doi:10.1016/j.ecresq.2020.05.009

Essex, M. J., Thomas Boyce, W., Hertzman, C., Lam, L. L., Armstrong, J. M., Neumann, S. M. A., et al. (2013). Epigenetic vestiges of early developmental adversity: Childhood stress exposure and DNA methylation in adolescence. *Child Development, 84*(1), 58-75. doi:10.1111/j.1467-8624.2011.01641.x

Evensen, K., Vik, T., Helbostad, J., Indredavik, M., Kulseng, S., & Brubakk, A. (2004). Motor skills in adolescents with low birth weight. *Archives of Disease in Childhood Fetal and Neonatal Edition, 89*(5), F451-F455. doi:10.1136/adc.2003.037788

Felitti, V. J., Anda, R. F., Nordenberg, D., Williamson, D. F., Spitz, A. M., Edwards, V., et al. (1998). Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. the adverse childhood experiences (ACE) study. *American Journal of Preventive Medicine, 14*(4), 245.

Friel, S., & Krieger, N. (2018). *Climate change and the people's health*. New York; Oxford: Oxford University Press.

Fries, A. B. W., Shirtcliff, E. A., & Pollak, S. D. (2008). Neuroendocrine dysregulation following early social deprivation in children. *Developmental Psychobiology, 50*(6), 588-599. doi:10.1002/dev.20319

Gosling, S. N., McGregor, G. R., & Lowe, J. A. (2008). Climate change and heat-related mortality in six cities part 2: Climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change. *International Journal of Biometeorology, 53*(1), 31-51. doi:10.1007/s00484-008-0189-9

Gunnar, M. R., & Nelson, C. A. (1994). Event-related potentials in year-old infants: Relations with emotionality and cortisol. *Child Development, 65*(1), 80. doi:10.2307/1131367

Hayes, K., & Poland, B. (2018). Addressing mental health in a changing climate: Incorporating mental health indicators into climate change and health vulnerability and adaptation assessments. *International Journal of Environmental Research and Public Health, 15*(9), 1806. doi:10.3390/ijerph15091806

Health Canada. (2021). *Health impacts of air pollution in Canada 2021 report.* Retrieved May 9, 2021, from https://www.canada.ca/en/health-canada/services/publications/healthy-living/2021-health-effects-indoor-air-pollution.html

Hertzman, C. (1999). The biological embedding of early experience and its effects on health in adulthood. *Annals of the New York Academy of Sciences, 896*(1), 85-95. doi:10.1111/j.1749-6632.1999.tb08107.x

Hertzman, C., & Boyce, T. (2010). How experience gets under the skin to create gradients in developmental health. *Annual Review of Public Health, 31*(1), 329-347. doi:10.1146/annurev.publhealth.012809.103538

Human Early Learning Partnership. (n.d.). *Mission, vision and goals.* Retrieved April 3, 2021, from http://earlylearning.ubc.ca/about/mission-vision-and-goals/#:~:text=HELP's%20goals%20are%20to%3A&text=Promote%20equity%20in%20children's%20developmental,lifelong%20health%20and%20well%2Dbeing%3B&text=Contribute%20to%20social%20change%20that,being%20of%20children%20and%20families.

Jakubicka, T., Vos, F., Phalkey, R., & Marx, M. (2010). *Health impacts of floods in Europe: Data gaps and information needs from a spatial perspective*

Keating, D., & Hertzman, C. (1999). *Developmental health and the wealth of nations*. New York, NY: Guildford Publications, Inc.

Lesnikowski, A. C., Ford, J. D., Berrang-Ford, L., Paterson, J. A., Barrera, M., & Heymann, S. J. (2011). Adapting to health impacts of climate change: A study of UNFCCC annex I parties. *Environmental Research Letters, 6*(4), 044009. doi:10.1088/1748-9326/6/4/044009

Li, X., Chen, Q., Zheng, X., Li, Y., Han, M., Liu, T., et al. (2019). Effects of ambient ozone concentrations with different averaging times on asthma exacerbations: A meta-analysis. *Science of the Total Environment, 691*, 549-561. doi:10.1016/j.scitotenv.2019.06.382

Maggi, S., Irwin, L. J., Siddiqi, A., & Hertzman, C. (2010). The social determinants of early child development: An overview. *Journal of Paediatrics and Child Health, 46*(11), 627-635. doi:10.1111/j.1440-1754.2010.01817.x

Masson-Delmotte, V., Zhai, P., Portner, H. -., Roberts, D., Skea, J., Shukla, P. R., et al. (2014). *Summary for policymakers* Cambridge University Press.

Natural Resources Canada. (2019). *Canada's changing climate report.* Government of Canada.

Olson, D. M., & Metz, G. A. S. (2020). Climate change is a major stressor causing poor pregnancy outcomes and child development. *F1000Research, 9* doi:10.12688/f1000research.27157.1

Ostry, A., Ogborn, M., Bassil, K. L., Takaro, T. K., & Allen, D. M. (2010). Climate change and health in British Columbia: Projected impacts and a proposed agenda for adaptation research and policy. *International Journal of Environmental Research and Public Health, 7*(3), 1018-1035. doi:10.3390/ijerph7031018

Paranjothy, S., Gallacher, J., Amlôt, R., Rubin, G. J., Page, L., Baxter, T., et al. (2011). Psychosocial impact of the summer 2007 floods in England. *BMC Public Health, 11*(1), 145. doi:10.1186/1471-2458-11-145

Philipsborn, R., & Chan, K. (2018). Climate change and global child health. *Pediatrics, 141*(6), 1-5. Retrieved from https://pediatrics-aappublications-org.ezproxy.library.ubc.ca/content/pediatrics/141/6/e20173774.full.pdf

Schnitzler, J., Benzler, J., Altmann, D., Mucke, I., & Krause, G. (2007). Survey on the population's needs and the public health response during floods in Germany 2002. *Journal of Public Health Management and Practice, 13*(5), 461-464. Retrieved from MEDLINE - Academic database. Retrieved from https://search.proquest.com/docview/68224391

Sheffield, P., & Landrigan, P. (2011). Global climate change and children's health: Threats and strategies for prevention. *Environmental Health Perspectives, 119*(3), 291-298. Retrieved from CrossRef database.

Shonkoff, J. P., Garner, A. S., Siegel, B. S., Dobbins, M. I., Earls, M. F., McGuinn, L., et al. (2011). The lifelong effects of early childhood adversity and toxic stress. *Pediatrics (Evanston), 129*(1), e232-e246. doi:10.1542/peds.2011-2663

Shonkoff, J. P., Boyce, W. T., & McEwen, B. S. (2009). Neuroscience, molecular biology, and the childhood roots of health disparities: Building a new framework for health promotion and disease prevention. *JAMA : The Journal of the American Medical Association, 301*(21), 2252-2259. doi:10.1001/jama.2009.754

Silk, Ann W., MD, MS, & Margolin, K., MD. (2018). Summary. *Hematology/Oncology Clinics of North America, 33*(2), 261-274. doi:10.1016/j.hoc.2018.12.004

Smith, J., Huq, S., & Klein, R. (2003). *Climate change, adaptive capacity and development*. London: Imperial College Press.

Smith, K., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., et al. (2014). Human health: Impacts, adaptation, and co-benefits. In U. Confalonieri, & A. Haines (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability* (pp. 709-754). Cambridge, United Kingdom: Cambridge University Press.

Thomson, K., Richardson, C., Gadermann, A., Emerson, S., Shoveller, J., & Guhn, M. (2019). Association of childhood social-emotional functioning profiles at school entry with early-onset mental health conditions. *Jama Network Open, 2*(1)

Tong, S. (2017). Flooding-related displacement and mental health. *The Lancet. Planetary Health, 1*(4), e124-e125. doi:10.1016/S2542-5196(17)30062-1

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., et al. (2018). *The 2018 report of the lancet countdown on health and climate change*. Published Online:

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Boykoff, M., et al. (2019). *The 2019 report of the lancet countdown on health and climate change*. Published Online.

World Health Organization. (2020). *Air pollution.* Retrieved November 19, 2020, from https://www.who.int/health-topics/air-pollution#tab=tab_1

World Health Organization. (2021). *Social determinants of health.* Retrieved April 25, 2021, from https://www.who.int/health-topics/social-determinants-of-health#tab=tab_1

Xu Rongbin, Yu Pei, Abramson Michael, Johnston Fay, Samet Jonathan, Bell Michelle, et al. (2020). Wildfires, global climate change, and human health. *The New England Journal of Medicine, Special Report*, 1-9. doi:10.1056/NEJMsr2028985

Xu, Z., Sheffield, P., Su, H., Wang, X., & Bi, Y. (2014). The impact of heat waves on children's health: A systematic review. *International Journal of Biometeorology, 58*(2), 239-247. doi:10.1007/s00484-013-0655-x

Appendices

Appendix A: Scoping Review Search Strategy

Web of Science database search:

"British Columbia"

AND: Temperature OR heat OR heatwave* OR forest fire* OR wildfire* OR bushfire* OR peat bog fire* OR vegetation fire* OR flood* OR inundation* OR ozone OR evacuat*

AND: health OR epidemiolog* OR morbidity OR mortality OR illness OR injury OR death OR disease OR hospital* OR urgent care OR ambulance* OR emergency OR physician visit*

Appendix B: Scoping Review Inclusion Criteria

During both screening stages (abstract and full-text) of this project's scoping review, the inclusion criteria were the same. Publications were required to have used data pertaining to heat or temperature, wildfires, smoke or particulate matter, evacuations, ozone, or floods. These data were required to be collected in or modelled for the province of British Columbia. Finally, these data were required to be collected during or modelled for any time between 2004 and 2020.