A Review of Predicted Climate Change Impacts on British Columbia’s Heritage Sites

by

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Abstract

Threats related to global warming will grow over the 21st century. In British Columbia, climate change is predicted to cause rising sea levels, dry, hot summers, wet, warm winters, and more extreme weather events. As the severity and frequency of impacts increase, so could the rate of heritage site degradation. I outline site types that may be affected by the change in climate conditions based on research in other areas of the world. I also attempt to obtain an overview of the vulnerability of heritage sites across the province by creating risk mapping. This approach predicted the location and severity of impacts at set times by overlaying climate modelling data and documented heritage sites using Geographic Information System (GIS) software. Specifically, geospatial datasets for coastal sensitivity, temperature, and precipitation modelling were compared with heritage sites to determine if they intersected. The analysis results indicated that many sites could be at risk and that many were affected by more than one climate change variable. The vulnerability of sites to the effects of global warming was further illustrated with examples of past changes from wildfire and mountain pine beetle infestation and the number of potential sites that could have been subject to damage or destruction. Using information from this study, heritage managers can choose where to focus resources and efforts to manage future impacts on heritage in the province.

Keywords: British Columbia; climate change; global warming; predictive modelling; heritage sites, archaeological sites; site destruction

Dedication

To all the little ears that listen to their elders’ stories.

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I first acknowledge that my research was conducted from the ancestral and traditional territories of the Coast Salish peoples–Sḵwx̱wú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) Nations. This study encompasses the unceded, ceded, and traditional territories of Indigenous and Métis peoples across British Columbia. I am grateful for the opportunity to conduct my research in your homeland and hope that it will in some way benefit future generations.

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List of Acronyms

ALeRT	Archéologie Littoral et Réchauffement Terrestre
BC Archaeology Branch	British Columbia Archaeology Branch
BCMECCS	Ministry of Environment and Climate Change Strategy
BCMoE	British Columbia Ministry of Environment
°C	degrees Celsius
CCCS	Canadian Centre for Climate Services
CMT	culturally modified tree
DINAA	Digital Index of North American Archaeology
DRIPA	Declaration of the Rights of Indigenous Peoples Act
GIS	Geographical Information System
GPS	Global Positioning Systems
Ha	hectare
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
Max	maximum
MFLNRO	Ministry of Forests, Lands, and Natural Resource Operations
MFLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Min	minimum
m	metre
mm	millimetre
MPB	Mountain Pine Beetle
pH	potential of hydrogen or power of hydrogen
Precip	precipitation
QGIS	Quantum Geographic Information Software
RCP	representative concentration pathway
SFU	Simon Fraser University
Temp	temperature
TIF	Tag Image Files
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNESCO WHC	United Nations Educational, Scientific, and Cultural Organization World Heritage Centre
UV	ultraviolet

Chapter 1.

Introduction

Currently, the number and severity of climate change threats to heritage sites in British Columbia are unknown. We know anthropogenic sea-level rise and progressively more extreme weather events continue to grow (Intergovernmental Panel on Climate Change 2014:64-65). In 2007 the United Nations Educational, Scientific and Cultural Organization World Heritage Centre (UNESCO WHC) released a report on predicting and managing climate change on World Heritage. The authors stated, “No one can afford to wait for all the research to be completed for guidance on the management of cultural heritage under climate change conditions” (2007:35). In place of research, the UNESCO WHC identified the importance of creating risk and vulnerability maps that overlay climate change prediction data and the location of heritage sites (UNESCO WHC 2007:35). The reason for doing so is to identify risks to heritage sites and to then use this information to develop adaptation and management strategies.

Heritage sites include historical or archaeological sites, objects, artifacts, features, landforms, and stratigraphy that contain physical evidence of cultural activities, including the remains of habitation sites, subsistence procurement sites, ceremonial or spiritual sites, historical structures, and abandoned wrecks1. Ancestral burials, shipwrecks older than two years, sites that predate 1846, and those of unknown age that may predate 1846 on provincial land are protected under the Heritage Conservation Act (HCA) (RSBC 1996, c.187). These sites cannot be purposely altered or disturbed without a permit issued under the HCA by the Provincial Archaeology Branch. Sites on federal land have no formal legal protection but are generally managed based on guidance and policies from different land authorities (e.g., First Nations, Parks Canada, Department of National Defence, Port Authority) (Pokotylo and Mason 2010:5). Along with legal protection, biological and physical environmental conditions affect whether sites are

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[1] I am aware that some First Nations dislike or object to the term “archaeological site” in reference to places where their ancestors lived out portions of their lives (see Lyons et al. 2022). I respect this. However, because of the nature of this study on the effects of climate change, “archaeological site” and “heritage site” are considered the most appropriate terms to refer to locations containing material remains of past activities.

preserved. Conditions such as temperatures, erosion, oxidation, acidity, vegetation, and organisms can be impacted by shifts in the climate (Wright 2016:257).

The effects of rising temperatures increase the likelihood of droughts and wildfires. Temperature rise can also lead to a shift in vegetation as native species die off in some areas and new species appear, altering ecosystems (Rockman et al. 2016:21). Changing temperatures threaten heritage sites as increased temperatures can affect the stability of archaeological sites when dry materials such as leather, bone, wood, and metal become brittle. Drought and heatwaves can result in receding lakes, rivers, and reservoirs, exposing sites once protected by water to wind and erosion and unauthorized collection or damage. Drying of artifacts and features may also lead to cracking or breakage as moisture is pulled from the artifacts (e.g., weakening cell structures of wood or leather) (Wright 2016:260). Melting permafrost, glaciers and ice patches could also expose preserved organics causing decay (Larsson 2021:198-199). Drier conditions could also mean sites are more susceptible to wind and water erosion or burning from wildfires which can alter or destroy site context by altering features and moving or damaging artifacts (Rockman et al. 2016:21-24). Wildfires can damage culturally modified trees, lithic artifacts (e.g., pot lidding, spalling), organic artifacts and samples (e.g., pollen, protein, radiocarbon), burn down historic buildings, blacken artifacts, melt glass and metal, and expose buried structures to wind and water erosion (Jones 1986:243,250). Increased temperature can also lead to changes in precipitation patterns.

In Europe, research on the impacts of climate change on heritage conducted under the NOAH’s ARK project identifies that water and not temperature is the main threat (Cassar 2016:121-122). Precipitation could be more frequent and heavier, causing flooding, landslides, and higher groundwater in winter and drought in summer (Maio et al. 2012:31). Features such as culturally modified trees could be irreparably damaged if the host tree dies due to drought, is burned in a wildfire, is infested by pests such as mountain pine beetle, or is knocked down by a severe storm, landslide, or eroding bank (Augustin 2007:25; Larsson 2021:197). Increased rainfall or spring run-off from high snowpacks could lead to site erosion, disrupting the context of sites, whereas landslides and riverbanks collapsing could lead to sections or entire sites being destroyed (Larsson 2021:187). Flooding or increased groundwater may lead to organic elements of a site, such as wood, fibres, bone, and leather, to decay or rot or, depending on how stable, it may help with preservation (Daly 2011:296). However, an increase in the wet and dry cycling through a change in precipitation patterns could increase the rate of decay and damaging materials through cracking and shrinking organic artifacts through repeated wetting and drying or a change in soil chemistry (e.g., increased salt levels at sites containing metal artifacts) (Larsson 2021:187). Wet-dry cycling along coastal areas due to sea level rise will also affect the preservation of materials such as bone, pollen, ceramics, and shells, causing data loss and impacting porosity and leaching of ions such as calcium (Wright 2016:260).

Coastal sites along the shore and underwater may be impacted by temperature, precipitation, and sea-level rise. As water levels rise, underwater sites are positioned further out to sea and susceptible to ocean currents, different environments, and marine organisms (Wright 2016:258). Changes in salinity, temperature, and acidity may cause organisms to grow on-site underwater structures, weighing them down to collapse or burrowing into wooden artifacts or structures and destroying their integrity (Spalding 2011:12, 14; Whiteright 2012:474; Wright 2016:261). A temperature change could alter acidity, salinity, and lower oxygen levels. Higher acid levels corrode metals (e.g., copper, lead, pewter, tin), weaken concreted iron (e.g., shipwrecks), and degrade glazes on ceramics (Spalding 2011:13; Wright 2016:262). Along the shoreline, saltwater intrusion could introduce new chemicals, such as salt, that may impact site stability by corroding artifacts and increasing the decay rate (Spalding 2011:13). An increase in the severity of storms will also impact shoreline and inland sites, especially as sea level rises (Wright 2016:259). Heavy wind and rain can fall trees, and if they grow in a site, the root ball could be pulled up, disturbing artifacts and features. Hurricanes or heavy wave action along water bodies can destroy or bury underwater sites if they move sediment, artifacts, and structures (e.g., shipwrecks) along the ocean floor (Ives et al. 2018:75, Spalding 2011:14). Storms can also cause shoreline collapse eroding sites, and scattering artifacts (Wright 2016:258). Heavy winter storms and freezing temperatures can damage porous artifacts and crack them through freezing and thawing. Heavy snow could weigh on historic buildings, causing them to collapse. An unknown number of valuable heritage sites and artifacts could be lost, with them, the opportunity for future study and an understanding of the past.

The heritage of British Columbia plays a significant role in understanding and appreciating the region’s cultural uniqueness and its communities (British Columbia

Heritage Branch 2021:6). Heritage sites also provide a “sense of place, identity, and aesthetic wellbeing to local populations” (Sesana et al. 2021:2). When these locations are lost or damaged, there are social impacts to consider related to the “negative psychological impacts experienced by many citizens and thus ultimately to a decline of community mental health. Conversely, those communities tend to recover faster from natural disasters where the key features of their cultural environment, the iconic buildings and sites have not been destroyed, or where areas associated with tangible and intangible heritage are quickly restored” (Spennemann 2022:3). There are also economic impacts from climate change effects on heritage. In Canada, approximately $145 million of revenue was attributed solely to historic sites (e.g., visitation) in 2017 and $218.6 million in 2019 (Canadian Heritage 2018:2; 2020:6). In 2017, British Columbia’s economy received $7.1 billion from cultural products (Statistics Canada 2019). Heritage institutions in British Columbia generated $225 million in revenue in 2015 and $263.6 million in 2019 (Canadian Heritage 2018:2; 2020:6). In the province, the heritage sector is estimated to have employed 3,842 people in 2015 and 4,419 in 2019 (Canadian Heritage 2018:44; 2020:46). However, the threat to heritage sites, the revenue they generate, and how we perceive belonging and cultural identity increases as sea levels rise and extreme weather events progressively worsen.

Determining how climate change[2] may adversely affect heritage sites is complex, often ill-understood, and for the most part, subjective. In British Columbia, there is a paucity of studies that focus on whether gradual changes in climate conditions, increased intensity and frequency of severe weather events, and sea-level rise could affect heritage sites exposed to these various climate stressors (British Columbia MFLNRO 2013:4; Sesana et al. 2021:20). In general, there is also limited guidance regarding how best to assess risk and adapt to climate change risks in an environment where knowledge of global warming impacts is continuously evolving, and damage or loss attributed to climate change is still ambiguous (Sesana et al. 2018:15). In the past, the risks to heritage from climate change have been established using three different

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[2] Climate change is defined by the United Nations as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” (United Nations 1992:7). In this thesis climate change is attributed to human activities rather than natural causes. I also use the terms climate change and global warming interchangeably throughout my thesis.

approaches to risk analysis (Carmichael 2018:4). The first method was developed by Daly (2014:268-280) and applied in Ireland to identify if individual sites were vulnerable to climate change. This process involved visiting sites and interviewing local community members to gauge their response to climate model projections. This was a valuable qualitative tool for experts in the field when determining vulnerability on a small scale.

The second risk analysis tool expanded on Daly's work and formalized vulnerability assessment using a climate change risk index that looked at site hazards, exposure, and sensitivity (Forino et al. 2016:235-236). The AleRT program in France[3] and the CITiZAN program in England[4] use this method to assess risk (Benlloch et al. 2017:81, Wragg et al. 2017:44). Using standardized evaluation forms, crews record field observations translated into number values to rank site vulnerability (Nimura et al. 2017:6-7). A mathematical calculation is then applied to the values to determine a classification of low, moderate, or high risk of climate-related damage to coastal heritage sites. This technique could easily be adapted and used in other areas of the world. However, the work involved in collecting the information can be time-consuming, and the user is limited to assessing one site at a time.

As an alternative to the first two risk assessment methods, a desktop vulnerability study can determine several climate change projection impacts for a greater number of sites. Fenger-Nielsen et al. (2020:1281) recognized that many heritage sites might be affected by various climate threats and, as such, more tools were needed to help heritage managers to develop regional strategies. Thus, the third method helpful in assessing risk across large regional and local areas involves completing regional assessments of multiple threats (Heilen et al. 2018:261). Regional assessments of multiple threats have been conducted by Heilen et al. (2018:261) for the coastlines of northern Germany and Georgia in the southeastern United States, and by Agapiou et al. (2015:230) for the Paphos area of Cyprus. Additionally, Anderson et al. (2017:2) assessed climate impacts on heritage sites listed in the Digital Index of North American

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[3] The ALeRT (Archéologie Littoral et Réchauffement Terrestre) program was developed in response to climate change impacts on coastal sites in France (Benlloch et al. 2017:81). This is a collaborative program that utilizes both local community volunteers and regional experts to assess coastal erosion on sites (Benlloch et al. 2017:82).

[4] The CITiZAN (Coastal and Intertidal Zone Archaeological Network) program in England combines training and outreach to build a network of volunteers that monitor and record coastal sites vulnerable to climate change (Wragg et al. 2017:44).

Archaeology (DINAA) database along the coast of Florida in the southeastern United States. The DINAA study was limited to sea-level rise. However, the results showed that climate change would affect thousands of heritage sites. Given the timeframe of the predicted changes, it was also determined that existing policies and procedures might not be sufficient to address the scale and magnitude of the issue (Heilen et al. 2018:262). The mapping produced by the study showing the sites affected by sea-level rise was a highly effective tool to educate people about the severity of climate change impacts on coastal sites in British Columbia and beyond.

Given that 58,113[5] registered heritage sites are located across British Columbia, which is 95 million hectares in size and consists of 25,725 kilometres of coastline, there is a need to analyze multiple climate change threats on a regional rather than individual scale. In this way I use GIS software QGIS to intersect climate projection model mapping and registered sites to determine the number that overlap with each model scenario. I use the results of this comparison to investigate whether heritage sites in British Columbia are vulnerable to global warming and if more research on or management of the physical effects of climate change is necessary. I aim to provide a high-level outline of current climate conditions, identify potential impacts to heritage sites from the changing climate, estimate the potential number of sites exposed to modelled climate changes, and recommend approaches and strategies to mitigate impacts to support climate adaptation efforts in the province. In this introductory chapter, I present my study's background and context, followed by the research problem, research aims, objectives and questions, significance of the study, and its limitations.

1.1. Background to the Study

Climate is essentially a calculation of the average annual weather of an area over many years (Moore et al. 2010:47). Climate change is understood as shifts in weather patterns and temperature. Although a natural process, the rapid changes in climate we have experienced since the Industrial Revolution and could experience in the future are primarily driven by human-induced greenhouse gas emissions (Cannings and Cannings 2015:81; IPCC 2022:35). The preservation of heritage sites mainly depends on relatively stable environmental conditions. Shifts in the climate can expose or make sites more

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[5] This is the total number of sites recorded in British Columbia in 2020.

vulnerable to decay or degradation (Boethius et al. 2020:1). Global warming is predicted to impact heritage sites around the world differently depending on their geographic setting, site type, condition, how developed an area is, exposure, overall vulnerability, and the degree of climate change adaptation that communities implement (Daly 2011:293; IPCC 2018:7; Shayegh et al. 2016:1-2). Boethius et al. (2020:1-5) and Anderson et al. (2017:2) have observed sites where preservation conditions (e.g., anaerobic, cool, frozen, wet) have been altered because of changing climate. Sites may start degrading or disappearing as effects such as wildfires, severe weather, sea-level rise, ground water fluctuations, drought, and temperature increase in frequency and intensity (Anderson et al. 2017:1-3; Friesen 2018:29-30). Heritage managers should identify the impacts of climate change on heritage sites and develop strategies to avoid or mitigate the adverse effects.

Anthropogenic climate change has caused precipitation and temperature patterns to change rapidly in British Columbia over the last century (Lemmen et al. 2016:6; British Columbia Ministry of Environment and Climate Change Strategy (BCMECCS) 2017:1-2; Rodenhuis et al. 2009:12-22). Specifically, there have been and may continue to be hotter, drier summers and warmer, wetter winters. Settings most at risk are those located underwater, along water bodies, and in wetlands, glaciers, frozen ground, and forested areas (Dawson et al. 2017:10-16; Hamrick 2018; Nicholas 2012:763,766; Union of Concerned Scientists 2018; Wright 2016:257). Climate change impacts vary but in general can cause physical and or chemical damage to heritage sites through modifications in land-use patterns and subsistence practices, an increase in the intensity and frequency of storms, sea-level rise, ocean acidification, flooding, glacial loss, heat waves, drought, increase in pests, wildfires, and changes in precipitation patterns (Friesen 2018:28; IPCC 2014:10, 2018:9-12; Lemmen et al. 2016:13; BCMECCS 2019:3-4). Conditions are predicted to worsen as sea levels rise, rainfall intensifies, temperatures increase, and extreme climate events become more frequent (Lemmen et al. 2016:15; IPCC 2022:35). This would exacerbate natural processes, such as decay and erosion, becoming a risk multiplier that places heritage sites at even greater peril.

1.2. Problem Statement

To date, there has only been one empirical study of projected climate change impacts on sites in the province, specifically the effect of sea-level rise on nearshore archaeological features in the Gulf Islands (Wyatt 2015). Information on the current state and potential impacts to sites of current and future climate conditions is critically important to understanding whether sites are vulnerable to global warming and developing strategies to mitigate impacts (Aird et al. 2019:14; Anderson et al. 2017:1). In the past, studies have been reactive in response to sites being impacted by severe climate change events, such as the mountain pine beetle (Dendroctonus ponderosae Hopkins) infestation in the 1990s, wildfires in 2017 and 2018, severe storms on Haida Gwaii in 2018, and the flooding near Williams Lake in 2020 (Cohen 2019:1-4; Dyok 2020). In response to these events, a great deal of emergency archaeological mitigation work has been conducted in various locations across the province.

Given the potential number of sites that could be impacted by climate change, preserving all may not be possible (Holtorf and Kristensen 2014:313), meaning that difficult choices will need to be made. The province has not formally established a process for prioritizing what sites should be protected or mitigated. The overall response to the effects of global warming is inadequate and heritage sites may not be protected (Aird et al. 2019:14; British Columbia Heritage Branch 2021:3; Tahltan Central Government 2020:22). Aside from severe climate events, the type, frequency, and extent of potential damage from future climate change on heritage sites in the province are still largely unknown (Aird et al. 2019:14). Most information on such effects comes from post-impact assessments conducted after changes have occurred and sites damaged or destroyed. As a result, it is impossible to develop the knowledge and skills essential to proactively manage negative outcomes from climate change on sites on a regional scale. The slow pace of knowledge development has hampered and might continue to hinder heritage managers in developing strategies and approaches needed to respond adequately. The magnitude and scale of the threat may leave many unprepared to manage rapidly deteriorating sites in terms of the skills and knowledge they need. Best practices would be for stewards of heritage sites to develop proactive and responsive strategies and skillsets that compliment each other. More proactive study and planning could help prioritize sites, identify areas of research and skills training needed, complete research on sites not under immediate threat, mitigate damage prior to impact, and develop management plans (Lipe 1974:242). Alternatively, reactive or “salvage” archaeological approaches can be used on sites under imminent threat based on previously developed management plans and research questions (Lipe 1974:234).

1.3. Research Goals and Objectives

Given the lack of research on how climate change may affect tangible heritage in British Columbia, this study was developed to identify vulnerable sites and recommend approaches and strategies for heritage managers in the face of climate change. To achieve this goal, I had four primary objectives:

1. to estimate the approximate number of heritage sites in British Columbia that may be affected by modelled climate change (e.g., relative to temperature, precipitation, coastal sensitivity);
2. to develop a general overview of how climate change could affect heritage sites by reviewing past studies;
3. to evaluate whether there is a benefit in using existing climate change models to identify vulnerable sites; and
4. to enhance the stewardship of heritage sites in the future by recommending improvements to climate change predictions and management of effects.

I employed various methods and tools to meet these objectives and answer the research questions. To determine the number of heritage sites located in areas with the potential to be impacted in the future, I used existing global warming model scenarios to conduct a quantitative analysis. I did this by comparing predicted scenarios for changes in precipitation, temperature, and coastal sensitivity from CanCoast and Canadian Centre for Climate Services (CCCS) model layers (e.g., coastal sensitivity 2090s, minimum temperature 2020, maximum temperature 2100) with registered location of heritage sites. I derived information on past climate change impacts by comparing site locations to geometries of forest fire and mountain pine beetle (MPB) infestation areas. I assessed the results of the dataset comparisons to provide a general overview of the impacts climate change may have on heritage sites in the province. I also evaluated these results to determine if a GIS is a valuable tool for identifying vulnerable sites. Previous efforts to manage climate change effects on heritage in the province, impacts on sites, predicted climate changes, and the model comparison results provided context to identify where improvements could be made to predict and manage site impacts.

1.4. Study Benefits

This thesis contributes to the body of knowledge on the management of climate change impacts on heritage sites by providing a preliminary analysis of site vulnerability. This could help address the current shortage of research in this area. It also offers real-world value to heritage managers in the province by providing information useful for making decisions on prioritization of heritage site protection to improve the preservation of significant values. By disseminating the results, the expected benefits of my research will be to:

1. raise awareness among heritage managers and the public of the impacts of climate change to heritage sites;
2. support affected communities, stewards of heritage, professionals, and government agencies in justifying why climate change impact on heritage sites needs to be addressed;
3. help identify areas where further study, monitoring, or mitigation are needed to tackle climate change impacts on heritage sites;
4. encourage the development of recommendations/guidelines that could improve future management or conservation of heritage sites; and
5. promote the use of archaeological tools such as climate change modelling to identify the impacts of climate change on heritage sites.

1.5. Thesis Organization

This thesis is organized into six chapters. In the first I provide a broad introduction to the topic and the motivation and goals for this research. I begin by describing the background information relevant to the study, including high-level information on climate change, the current climate in British Columbia, and how this may affect heritage sites. The following section briefly reviews the response to managing recent damage to sites from climate change events and states why this may be problematic in the future due to a lack of information on the extent of the damage. Next, the general goals and research objectives focus on determining the approximate number of sites vulnerable to global warming using available modelling data and outline four main research questions. Finally, I introduce the study benefits, focusing on identifying sites affected by climate change to improve impact management.

Chapter 2 presents more detailed background information on current and expected climatic conditions and prospective consequences on British Columbia's heritage. There are five parts to this chapter: a description of the province's microclimates and biogeoclimatic zones; a discussion of notable climate change events over the past three decades; an outline of the most significant climate change risk events, and a summary of the results of a risk assessment study conducted to identify the most significant risks to heritage sites in the province; a description of previous climate change studies on heritage site management in the province; and an explanation of how changes in the climate and different climate change events could potentially impact sites.

Methods and tools used to achieve study objectives and answer research questions are described in Chapter 3. The first section outlines the source of the data used for the analysis and how the datasets were selected. This section also explains how climate change models and heritage datasets were collected and analyzed and describes the data for the location of heritage sites and climate change model databases, including coastal sensitivity, temperature, and precipitation. The next section outlines the procedures used to analyze the datasets in relation to the number of vulnerable sites and the types of impacts anticipated. The final section discusses the limitations of the study.

Chapter 4 summarizes the key findings of the data analysis of forecasted climate change modelling and archaeological site locations. The available climate change model databases include coastal sensitivity, temperature, and precipitation in three-time steps (i.e., current, 2050, and 2090-2100). A description of the analysis of these databases is presented. I then explain the results of comparing past climate change impact spatial areas for wildfire and MPB infestation with site locations.

The research objectives and research questions are discussed in Chapter 5. To aid the discussion, it includes specific examples from the model intersection. Finally, Chapter 6 presents conclusions with 25 recommendations for future studies. Proactive measures to reduce the worst consequences and improve future multi-threat climate change models are emphasized. This chapter also highlights the benefits and applications of the research.

Chapter 2.

Impacts of Past, Current, and Future Climate Conditions on Heritage Sites

This study reviews the effects of modelled climate predictions in British Columbia. This chapter presents relevant information I compiled and considered while researching environmental factors affecting heritage sites. I begin with an outline of the current climatic conditions and diversity of the various regions across the province. To better understand whether the effects of global warming have already impacted sites in the province, I include information on wildfires and MPB infestations over the last thirty years. Next, I summarize the changes anticipated by predictive model results of temperature, precipitation, sea-level rise, and the associated climate change risk events. I then summarize previous research on climate change in the area, emphasizing emergency response, melting ice patches and glaciers, and rising sea levels. The final section discusses the potential impacts on sites from precipitation, temperature, coastal sensitivity, and wind.

2.1. Current Climate

British Columbia has a highly variable climate, which is influenced by ocean currents[6], landforms[7], elevation, and weather[8] (Cannings and Cannings 2015:70-75; Hebda 1995:56). The five “physiographic regions” in the province (Hebda 1995:56; Moore et al. 2010:47) are the Coastal Mountains and Islands, Interior Plateau and Mountains, Southern Plateau, Northern Great Plains, and South Columbia and Rocky

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[6] The Pacific Ocean moderates the climate along the coast of British Columbia. The Subarctic and North Pacific are the two dominant ocean currents. The winds and ocean salinity mainly influence the currents. The Subarctic current splits into the California and Alaska currents. In winter, when winds strongly blow southwest, a third current moves north along the south coast called the Davidson current, bringing warm water from the North Pacific (Cannings and Cannings 2015: 61-64).

[7] The coastal mountain range blocks off the interior from the moderating influence of the Pacific Ocean. As winds tend to blow west across the province, there is more rainfall on the west side of mountain ranges than in the east (Cannings and Cannings 2015: 70-71; Pigott and Hume 2009: 118-119).

[8] “Weather” includes wind speed and direction, humidity, atmospheric pressure, air temperature, and precipitation (Moore et al. 2010: 47).

Mountains. Each region includes several macro-climates with distinctive vegetation or “biogeoclimatic zones.” A biogeoclimatic zone is a geographic area that has a relatively homogeneous macro-climate and whose dominant vegetation is most affected by climate, topography, land cover, precipitation, and temperature (Meidinger and Pojar 1991:22-23).

The Coastal Mountains and Islands region includes Vancouver Island, Haida Gwaii, and the Coastal Mountain Ranges, which extend along the entire coastal mainland (Cannings and Cannings 1999:40-41; Hebda 1995:56). The ocean moderates the climate of this region, where the summers are cool to mild, wet on the outer coast and dry on the inner coast (Moore et al. 2010:50). The winters are mild and wet on the outer coast and moist on the inner coast, and the average annual precipitation ranges from 800 to 4000 mm (Cannings and Cannings 2015:70; Moore et al. 2010:50; Pigott and Hume 2009:133). In July, the average daily temperature ranges from 10 to 25°C and in January, the average daily temperature ranges from -14 to 5°C (Cannings and Cannings 2015:70-71; Pigott and Hume 2009:124. This moist, mild climate supports Interior Cedar-Hemlock, Coastal Western Hemlock, Mountain Hemlock, and Alpine Tundra biogeoclimatic zones (Hebda 1995:60).

The Interior Plateau and Mountains region is east of the Coastal Mountains and west of the Columbia and Rocky Mountains. It extends from the Yukon border in the north to the Washington border in the south (Hebda 1995:56). The summers in the Interior Plateau are warm and dry, and the winters are mild and moderately dry (Moore et al. 2010:50). In the Interior Plateau's central and northern portions, summers and winters are colder and drier than in the southern portion of the Plateau (Moore et al. 2010:50). In July, daily average temperatures range between 10 and 25°C in the north and from 16°C to more than 25°C in the south (Cannings and Cannings 2015:71; Pigott and Hume 2009:125). In January, the average daily temperature in the north ranges from -29 to -19°C and in the south from -19 to -5°C (Cannings and Cannings 2015:70; Pigott and Hume 2009:124). The average annual precipitation ranges from 201 to 1200 mm (Cannings and Cannings 2015:70; Pigott and Hume 2009:133). The biogeoclimatic zones in the northern reaches of the Interior Plateau include Sub-boreal Pine-Spruce, Sub-boreal Spruce, and Interior Douglas Fir (Cannings and Cannings 1999:101; Hebda 1995:68). Within the central portion of the Interior Plateau, which is warmer, Mountain Spruce and Engelmann Spruce-Subalpine Fir biogeoclimatic zones are found (Cannings and Cannings 1999:101; Hebda 1995:68). The biogeoclimatic zones in the Southern Interior include Bunch Grass, Ponderosa Pine, Interior Douglas Fir, Mountain Spruce, Engelmann Spruce-Subalpine Fir, Interior Cedar-Hemlock, and in higher elevations Alpine Tundra (Cannings and Cannings 1999:101; Hebda 1995:65).

In the northeast corner of the province, the Northern Great Plains region extends along the border with Alberta and the Yukon. The summers in this region are warm and dry, the winters cold and dry (Moore et al. 2010:50). In July, the average daily temperature ranges from 16 to 25°C (Cannings and Cannings 2015:71; Pigott and Hume 2009:125). In January, the average daily temperature ranges from -29 to -19°C (Cannings and Cannings 2015:70; Pigott and Hume 2009:124). The average annual precipitation ranges from 201 to 800 mm (Cannings and Cannings 2015:70; Pigott and Hume 2009:133). Boreal White and Black Spruce dominate the biogeoclimatic zones in the Northern Great Plains and Alpine Tundra and Spruce-Willow Birch along the western margins (Cannings and Cannings 1999:101).

The Southern Columbia and Rocky Mountains region encompasses the province's southeast corner bordering Alberta and Washington. Summers in the Southern Columbia and the Rocky Mountains are warm and moderately dry, the winters cool to cold and moderately wet (Moore et al. 2010:50). In July, the average daily temperature ranges from 10 to greater than 25°C (Cannings and Cannings 2015:71; Pigott and Hume 2009:125). In January, the average daily temperature ranges from -19 to -5°C (Cannings and Cannings 2015:70; Pigott and Hume 2009:124). The average annual precipitation ranges from 401 to 1600 mm (Cannings and Cannings 2015:70; Pigott and Hume 2009:133). Ponderosa Pine and Interior Douglas Fir dominate these biogeoclimatic zones at lower elevations and Interior Cedar-Hemlock, Engelmann Spruce-Subalpine Fir, Mountain Spruce, and Alpine Tundra dominate at higher elevations (Cannings and Cannings 1999:101; Hebda 1995:69).

Several environmental factors affect biogeoclimatic zones, including vegetation, soils, and topography. Vegetation and plant communities transform based on fluctuations in the climate (Brown et al. 2017:616). The primary catalyst for anthropogenic climate change is increased amounts of greenhouse gas emissions (e.g., chlorofluorocarbons, tropospheric ozone, carbon dioxide, methane, and nitrous oxide) into the atmosphere from human activities[9] causing temperature rise (Cannings and Cannings 2015:81; Watson et al. 1992:29-30). Alterations in atmospheric and ocean temperature have a domino effect of interrelated climate changes, a phenomenon known as global warming or global weirding (Cannings and Cannings 2015:82). As greenhouse gas emissions rise, the rate of climate transformation increases. In the last thousand years, the current climate shift rate has been highest in the last 30 years (Cannings and Cannings 2015:81). Adaptation by heritage managers to address impacts to values determined to need protection, or mitigation, may be challenging due to the speed of change. Unfortunately, geographic datasets showing how biogeoclimatic zones will transform in the future was not available to include in my analysis. However, it is good to note that vegetation in biogeoclimatic regions has been transforming which has already led to impacts to heritage sites due to MPB infestation and wildfires.

2.2. Notable Climate Change Events Over the Last Century

Since 1900, average temperatures in British Columbia have risen 2°C in the winter and 1°C in the summer, and the frost-free period has increased by three to four weeks (Cannings and Cannings 2015:81). As a result of this warming trend, tree species' habitats have already changed in the northern and southern interior biogeoclimatic zones (Hamann and Wang 2006:2773). Ecosystem climate models predict tree ranges will expand north at approximately 100km per decade, and some coniferous tree species will lose much of their habitat (Hamann and Wang 2006:2784). There have also been two noteworthy ecological changes events over the last thirty years: the MPB epidemic and severe wildfires.

MPB

MPB or *Dendroctonus ponderosae* may be one of the most destructive types of bark beetle (Nikiforuk 2011:57). This small beetle attacks mature ponderosa or lodgepole pine, boring through the bark and colonizing trees by mining the phloem and laying eggs (Nikiforuk 2011:46-49). Once the eggs hatch the larvae eat the phloem (Nikiforuk 2011:46-49). A MPB attack on a lodgepole pine tree is fatal. Once dead, the

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[9] Human activities that release greenhouse gases contributing to global warming include agriculture, deforestation, cement production, and burning fossil fuels (Watson 1992:31-42),

tree’s nutrients return to the forest, and the beetles fly to another vulnerable tree (Province of British Columbia n.d.:9). Cold temperatures in winter, a tree's natural resistance to beetle attack, predators, and competition for space all control beetle population size and keep them from overbreeding and attacking too many trees and spreading beyond their natural range (British Columbia Ministry of Environment (BCMoE) 2016:42-43, Nikifuruk 2011:100-101). This system of natural forest management, in which beetles and trees coexist, is kept in balance in particular climate conditions (Murdock et al. 2013:75-76). However, the speed of projected climate change means beetle populations may grow, and forest ranges not normally impacted may become vulnerable to attack (Murdock et al. 2013:75-76). Past changes that have caused imbalances include:

1. increased temperature in the spring and fall months, allowing growth in beetle population due to expanded habitat;
2. decreased precipitation or drought-like conditions stressing trees and making them less resilient to MPB attacks; and
3. fire suppression work over the last century causing an abundance of older tree stands to be susceptible to MPB attacks (Burleigh et al. 2014:50-51; Hamann and Wang 2006:2773; Murdock et al. 2013:75-76; Province of British Columbia 2020a).

From 1999 to 2015, British Columbia endured the most extensive MPB outbreak witnessed in Canada (BCMFLNRO n.d.). Approximately 18.1 million hectares of pine trees were affected (BCMFLNRO n.d.). MPB most commonly attack mature lodgepole pine but may also attack Western white pine, whitebark pine, and ponderosa pine trees (Burleigh et al. 2014:50-51). MPB outbreaks are associated with a change in climate over the last century. Forests are vulnerable to other impacts, including damage caused by other insects and tree diseases (Murdock et al. 2013:76).

Wildfires

Wildfire conditions are influenced by environmental and physical factors (Brown et al. 2017:615). Key environmental settings consist of topography, fuel load, and weather. In the summer months, when temperatures are warm and precipitation levels are low, wildfire activity increases in areas such as western North America (World Meteorological Organization 2019:23). An increase in summer temperatures and reduction in precipitation means both the length of the fire season and the size of the areas burned have increased and may grow in the future (Brown et al. 2017:615). Wildfires burn at various temperature ranges depending on the soil and fuel source (Busse et al. 2005:273). For example, areas with a large amount of fuel, such as unharvested MPB-infested areas with thicker litter mats from fallen needles and dead standing timber, may burn hotter, and as a result, heritage sites could have more damage than areas that MPB has not attacked. Approximately 2.5 million hectares of forest burned in British Columbia between 2017 and 2018 (Province of British Columbia 2020b). In 2021, 869,279 hectares burned, making it the third-worst fire season on record for the region (Province of British Columbia 2020b).

2.3. Predicted Anthropogenic Global Warming Impacts in British Columbia

Documented climate changes include impacts in precipitation and temperature patterns, sea-level rise, and extreme weather events (Lemmen et al. 2016:6; BCMECCS 2017:1-2, 2019:1). To better manage impacts to heritage sites, it is essential to understand the consequences of the climate crisis and identify potentially vulnerable sites and biogeoclimatic zones, mainly because the impact can vary depending on environmental settings[10]. The effects of global warming are difficult to forecast since predictions are frequently revised using new or improved datasets and various other factors such as variation in greenhouse gas emission levels impact the rate, severity, and type of change. It can also be challenging to determine how heritage sites may be affected because many other factors are involved, and heritage professionals need this information before making decisions (Wright 2016:258).

Climate change modelling studies have shown that trends in model simulations developed between the 1970s and 2007 were fairly accurate in their prediction of global warming (Hausfather et al. 2020:6-8). However, the early models and, to some extent, current models, are not precise enough to predict how and when climate change could affect individual locations. How predicted changes in temperature, precipitation, and sea-level rise might alter the climate is outlined below.

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[10] In this context, “environment” refers to geographic areas, particularly those influenced by human activity.

2.3.1. Predicted Changes in Temperature, Precipitation, and Sea-Level Rise

In British Columbia, using an unbiased downscaled global climate model output and an RCP of 8.5 a temperature increase of 1.3° to 2.7°C is expected by 2050, with a maximum of 4.5°C by the end of the century (BCMoE 2016:41, British Columbia BCMECCS 2019:50, 71). A difference of a few degrees of warming would significantly affect systems sensitive to any variability, such as water cycling, precipitation patterns, weather, and terrestrial and marine ecosystems (National Research Council 2010:33-52). The impacts expected from these changes are descried below and in Table 1.

Across the study area, the predicted annual rainfall is expected to rise from 4 to 17% by 2080 (BCMoE 2016:16). Precipitation would rise from 5 to 23% in the winter months (BCMoE 2016:16). During the summer, drought conditions could worsen, with northern areas drier and southern areas wetter (BCMoE 2016:15-17). Increased temperatures in winter and summer may result in a 30 to 50% reduction in the glacial area in British Columbia by 2050; by 2100, 70% of glaciers might have melted, and most small glaciers in the south may be gone (BCMoE 2016:4; BCMECCS 2019:50). Globally, as glaciers and ice caps melt at an increased rate, sea levels will rise.

Summers and winters would become warmer, extending the growing season, changing species and habitats, and endangering flora and fauna adapted to cold climates (Hamann and Wang 2006:2784). A warmer winter would increase the frequency and intensity of insect outbreaks and infectious tree diseases, affecting forests and other ecosystems. When precipitation decreases in summer, river flows are lowered, which can cause local drought, stress, and loss of trees and bogs, resulting in habitat changes and plant species that are not drought resistant, such as cedar trees, being lost. As a result of drought conditions, fires are also more likely to occur and be more severe and are more widespread. Additionally, decreases in summer precipitation can increase ground movement, soil moisture loss, and soil erosion.

Increasing winter precipitation in conjunction with warmer temperatures may cause early spring runoff and flooding, which would increase erosion and bank instability along waterways and put added pressure on buildings and infrastructure (BCMoE 2016:16). For example, a result of heavy rains in 2021, landslides and flooding damaged infrastructure and utilities in British Columbia. Precipitation increases erosion along the coast and damages intertidal bogs and intertidal zones. Increasing water tables, higher groundwater levels, and more pollutants leaching from soils and flushing into waterways could change soil moisture content and chemistry (Boethius et al. 2020:5,17-19). In winter, the increase in precipitation on land may affect the frequency and intensity of storms and damage buildings and infrastructure (BCMECCS 2019:66,105,280). Warmer winters and changing seasons lengthen growing seasons, alter flora and fauna, increase ground movement, raise soil moisture variability, and change groundwater and groundwater tables.

Environmental factors are considered when evaluating the vulnerability of coastal areas to global warming. These include geological processes (e.g., glacial rebound, deltaic sinking, and plate tectonics), topography (e.g., slope, elevation), ground ice, tidal range, wavelength, wave height, ocean currents, melting of glaciers, increasing temperature, and predicted sea-level height (Foreman et al. 2014:26-27; Manson et al. 2019:3). Using coastal sensitivity modelling based on CanCoast 2.0, I identified areas with the potential to be destabilized, flooded, eroded, or to experience sediment movement (Manson et al. 2019:1-2). Modelling results show a high level of regional variability, resulting from global sea-level change and regional and local processes, such as tectonic shifts and post-glacial rebound (Bornhold 2008:6).

Modelling indicates coastal areas of British Columbia could experience sea-level rise of 26 to 98 cm by 2100 (BCMoE 2016:31-32,41). More frequent and severe flooding and other weather events would cause storm surges, high waves, and winds. Not all coastal areas may be affected equally by sea-level rise. Some areas are more affected by plate tectonic shift and isostatic rebound, causing land to rise and fall at different rates. Additionally, other factors may influence the level of impact from sea-level rises, such as human activities, geomorphological and hydrological processes, subsurface geology, and changes in slope and elevation (BCMoE 2016:31-32). Buildings could be damaged, existing infrastructure stressed, and saltwater incursion may contaminate aquifers and low-lying areas as sea levels rise (ICF 2019:14). The south coast of Vancouver Island, the Squamish Delta, the Fraser River Delta, Esquimalt, and Haida Gwaii's east coast are anticipated to be most sensitive to climate change in the future (Lemmen et al. 2016:216, 248). Other areas are also at risk, such as southern Vancouver Island and Prince Rupert, the west coast of Vancouver Island, and the mid-coast near Bella Bella (Lemmen et al. 2016:216,248).

Table 1. Impacts from predicted changes in temperature, precipitation, and sea-level rise.

Increased summer temperatures	Increased winter temperatures	Decreased summer precipitation	Increased winter precipitation	Rise in sea-level	Increase in extreme weather events	Changes in seasonality
Increased risk of drought more severe in the south than the north Melting of glaciers and ice caps Change in species and habitats Risk of losing cold adapted flora and fauna	Increased tree pests and disease Longer growing season	Increase in low river flows Increased drought Reduction in soil moisture Habitat change Increase in ground movement and infrastructure damage Increase in drought stress to trees and bogs Increase loss of trees Increased fire risk Change in plant species	Increase in snow or rainfall Increase in flooding and flood risk Increase in utility and infrastructure damage Increase in soil erosion Increase in pollutant leaching and flushing Changes in soil chemistry Increase water table, groundwater, and water logging of soils Reduction in bank stability and landslide risk Increased erosion and damage to intertidal zones and bogs	Increase in flooding and erosion Increase loss of coastal areas Increase saline intrusion Loss of mudflats and coastal marshes	Increased frequency and intensity of storms in winter Increased risk of drought Risk to cold adapted flora and fauna Change in species and habitats	Introduction of new flora and fauna Increased variability in soil moisture Increase in ground movement Change in flora and fauna Extended growing season Change in water table and groundwater

Adapted from: National Research Council 2010:33-52; BCMoE 2016:25-94; 3-47; and BCMECCS 2019:4

2.3.2. Most Significant Climate Change Risk Events to Heritage sites

In 2018, the British Columbia Auditor General conducted an audit to “determine whether the B.C. government adequately manages the risks posed by climate” (Auditor General of British Columbia 2018:9). That study determined a comprehensive risk assessment had not been completed, a refined adaptation plan did not exist, and ministries had not completed deliverables outlined in the adaptation strategy (Auditor General of British Columbia 2018:10). The reason for these shortcomings was determined to be a perceived lack of mandate and financial and staffing resources (Auditor General of British Columbia 2018:10).

In the Preliminary Strategic Climate Risk Assessment conducted by the British Columbia BCMECCS in 2019, climate risk events and consequences were identified based on a framework developed by ICF Climate Solutions (ICF 2019:2-7). Risk events can have discrete or ongoing causes (ICF 2019:15). *Ongoing risk* causes include global warming events such as sea-level rise and changes in temperature or precipitation patterns (ICF 2019:15). *Discrete risk* causes include floods, severe storms, and wildfires (Anderson et al. 2017:1-3; ICF 2019:15). The consequences of risk events are divided by ICF into six categories: health, social functioning, cultural resources, natural resources, economic vitality, and government costs (ICF 2019:19). This framework defines cultural resources as being “work of human art, an object, or a place that is directly associated, based on its heritage value, with an important aspect or aspects of human history and culture” (ICF 2019:19).

ICF named fifteen significant risk events (ICF 2019:14). Table 2 presents a ranking scale of consequences, ranging from “minor” to “catastrophic” for each risk event. "Catastrophic" indicates the destruction of an object or site. For those with a minor consequence ranking, damage may be repairable, or work could be conducted to restore the site within a short time (i.e., a few days) (ICF 2019:19). For cultural resources, the ICF assessment determined the consequences of melting glacial, ocean acidification, and severe coastal storm surge risk events were moderate to major. In addition, multiple coinciding events, interactions between events, and the worsening climate could compound effects and place sites under further threat (Fatorić and Seekamp 2019:689; ICF 2019:99; Lemmen et al. 2016:15). The report states cultural resources were not evaluated during the risk assessment due to insufficient information and the need for

Indigenous consultation (ICF 2019:3, 6, 12). As a result, the ICF assessment was incomplete. However, the report did identify glacial melt, ocean acidification, and coastal sea surges would have the most detrimental effects on cultural heritage.

Table 2. Risk assessment findings.

Significant risk event	Risk level	Consequence	Likelihood	Change in likelihood due to climate change by 2050
Severe riverine flooding	Medium	Major	Unlikely	Medium
Moderate riverine flooding	Medium	Moderate	Possible	Medium
Extreme precipitation and landslides	Medium	Minor	Possible	Medium
Seasonal water shortages	High	Moderate	Almost certain	Medium
Long-term water shortages	High	Major	Possible	Low
Glacial melt*	Medium-High	Moderate	Almost certain	High
Ocean acidification*	High	Moderate	Almost certain	Medium
Saltwater intrusion	Medium	Minor	Likely	Medium
Severe coastal storm surge*	Medium	Major	Unlikely	Medium
Heat wave	High	Major	Likely	High
Severe wildfires	High	Major-Catastrophic	Likely	High
Loss of forest ecosystems	Medium	Moderate	Possible	Low
Reduction in ecosystem connectivity	High	Moderate	Likely	Low
Increase in invasive species and pests	Medium	Minor	Almost certain	High
Increase in the transmission of diseases	Low	Minor	Unlikely	High

* Cultural resources were assessed by ICF as having the highest consequence. Table adapted from ICF 2019:50,55,61.

2.4. Previous Studies of Climate Change Impacts on Heritage sites

I divide studies previously conducted in British Columbia and nearby areas about global warming's impact on heritage into three main categories. I begin with examples of heritage management in emergencies such as wildfires, severe storms, flooding, and landslides. Next, I examine discoveries made due to receding glaciers and ice patches within and close to the province's northern border with Yukon. Finally, I summarize the results of a recent study conducted on the impacts of sea-level rise on an archaeological site in the southern Gulf Islands to illustrate previous research conducted in the region.

2.4.1. Emergency Response

During the 1999-2015 MPB outbreak, archaeological assessments and salvage work took place primarily in response to access, logging, and danger tree removal (British Columbia Ministry of Community Development, n.d.). Affected First Nations, the British Columbia Ministry of Forests, British Columbia Range Branch, and British Columbia Archaeology Branch collaborated to conduct remediation work to restore damage caused by wildfires in 2017-2018 and 2021 (e.g., fire breaks, infrastructure replacement, access construction, post impact assessments) (Dickson-Hoyle and John 2021:154). Emergency work had also been conducted ad hoc in response to natural events including severe storms, erosion, and flooding from 2018 to 2021. The Haida Nation and Parks Canada conducted an archaeological assessment and remediation work in response to a severe storm that damaged the SGang Gwaay World Heritage Site on Haida Gwaii in 2018 (Cohen 2019:3). After the Fraser River flooded near Williams Lake in 2020, a post-impact assessment was conducted that confirmed several sites were exposed. Furthermore, the severe flooding and landslides in southern portion of the province[11] in late 2021 likely damaged many sites. Such events are likely to become more intense and frequent (Cohen 2019:1-4; Dyok 2020).

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[11] Flooding occurred in the Squamish-Lillooet region, Along the Coquihalla River, Hope, Spences Bridge, Nicola River, Coldwater River, Tulameen River, Similkameen River, Fraser Valley, and Sumas Prairie.

2.4.2. Melting of Glaciers and Ice Patches

Frozen, cold, and wet conditions, such as those found in association with glaciers and ice patches, potentially allow for preserving organic heritage artifacts, features, and ancestral human remains for hundreds or thousands of years. After the Little Ice Age ended in British Columbia in mid 1800's glaciers began retreating (Cannings and Cannings 2015:103; Smith 2000:139). Globally the rate of glacial melt has increased nearly two-fold in the last twenty years (Hugonnet et al. 2021:728). As glaciers melt, these well-preserved sites become exposed to an aerobic environment, and organic elements decay rapidly. These discoveries have spurred researchers to document vulnerable sites while they still exist in the region and include:

- a 400-year-old hafted arrow found in Tweedsmuir Park at the Tsitsutl glacier in British Columbia in 1924 (Keddie and Nelson 2005:113; Mackie et al. 2010); and
- ancestral remains of Kwäday Dän Ts'ìnchini in Tatshenshini-Alsek Park in northern British Columbia in 1999[12] (Hebda et al. 2012:5; IUCN World Heritage 2020:3-12; Turner and Clifton 2009:187).

In 2019, the Tahltan Central Government Land department examined ice patches in Mount Edziza Provincial Park for heritage sites[13]. On Mount Edziza, there is a large concentration of well-known, significant, and high elevation archaeological sites located in the subalpine and alpine (Fladmark 1985:3; Reimer 2015:419). Those sites containing organic objects have been negatively affected by climate change. For example, a melting ice patch recently exposed perishable artifacts made of antler, birch bark, wood, and hide[14] (Tahltan Central Government 2020:22-24). The Mount Edziza investigation was one of the first studies explicitly researching the direct impacts of climate change in the province. The study recommended global warming impacts to sites on Mount Edziza should be managed under the British Columbia HCA. The study yielded outlined three

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[12] Yukon authorities were notified about the remains of Kwäday Dän Ts'ìnchini by hunters. It was later determined that the discovery was on the British Columbia side of the border. On the Yukon side of the border, the Yukon Ice Patch project which began in the late 1990s has had numerous additional discoveries have been made by surveying melting ice patches (Hare et al. 2011:2-4). Survey work has identified organic and inorganic artifacts associated with large concentrations of caribou dung (Hare et al. 2014:3,6,8).

[13] , The Mount Edziza Provincial Park study was funded by BC Parks.

[14] Some organic artifacts have been left in situ since they have a high preservation and analysis cost.

recommendations: 1) a provincial management policy be developed; 2) Mt. Edziza be designated a World Heritage site, and 3) more frequent survey and monitoring work be conducted (Tahltan Central Government 2020:27). The Tahltan Central Government, the Province, Skeena Resources Limited, The Nature Conservancy of Canada, and BC Parks have agreed to make this a conservancy to protect the lands (BCMECCS 2021).

2.4.3. Sea-Level Rise

Sea-level rise has and is expected to further impact clam garden sites in the Gulf Islands (Wyatt 2015:11). Clam gardens are rock-walled archaeological rock walled features built by First Nations over hundreds to thousands of years to replicate natural habitats and increase the number of clams viable for harvest (Wyatt 2015:11). Wyatt used GIS analysis, existing climate change modelling, and sampling data to study past and future changes at Salt Spring Island and Russell Island. Wyatt noted (2015:17) that sea-level rise impacts shell midden sites in the Gulf Islands. In addition, Wyatt (2015:28-29) identified sea-level rise, king tides, more severe storms, sea surges, coastal flooding, wave overtopping, rain runoff, and wind and wave action may all have damaging effects on heritage sites in the future. Her study concluded that past and future climate change modelling was valuable and could contribute to knowledge on the age and location of previously unrecorded features and would be vital for communicating impacts to a broad audience and strategizing coastal mitigation (Wyatt 2015:60-61). Parks Canada incorporated information from the study into park resource plans, outreach, and education programs, and completed a five-year study to restore two clam gardens (Wyatt 2015:17-18).

2.5. Climate Change Events with Potential to Impact Sites

If predicted trends in precipitation, temperature, and coastal sensitivity identified in climate change models are accurate, many heritage sites could be at risk of destruction or disturbance. There may even be cumulative impacts on sites resulting from multiple climate risk events. Impacts may vary from site to site depending on the intensity and frequency of climate events, type of environment, and site type (Augustin 2007:24). Here, I outline how changes in temperature, precipitation, and coastal sensitivity are expected to impact archaeological sites and features and built structures.

Table 3 summarizes anticipated effects to heritage sites. Given the limited number of studies on impacts from climate change to sites in British Columbia, this information is modified from research conducted in other parts of the world and examples of recent global warming events in the province.

2.5.1. Precipitation

Changes in precipitation patterns can cause prolonged wet or dry periods, flooding, extreme weather, severe coastal storm surge, altered water table, ground saturation, or groundwater levels, shifts in humidity cycles, ground saturation, acid rain, and ocean acidification (Augustin 2007:25; Daly 2011:300; Rockman et al. 2016:21-24). In British Columbia, impacts from increased precipitation can be catastrophic, as seen in the fall of 2021 when floods and landslides damaged an unknown number of heritage sites due to high levels of precipitation in the interior and along the coast.

Among the sites known to have sustained impacts were the Othello Tunnels (DiRi-116[15]) located in Coquihalla Canyon Provincial Park. This registered historic site is listed on the Canadian Register of Historic Places (BCMoE n.d.). Built in 1914, the railway tunnels played a role in the development of the province (BCMoE n.d.). In 2021 mud and trees were carried upriver through the tunnels when the Coquihalla River overflowed its banks (Kelly 2021). The water and debris caused extensive damage to the tunnel structures (Kelly 2021). Post-flood clean-up activities and water damage (e.g., mold, rot, corrosion) could further damage the Othello Tunnels (Augustin 2007:25; Rockman et al. 2016:22). Increased precipitation levels in other areas of the province could also lead to site erosion along flood channels, destabilization of sites due to ground saturation, landslides, and direct damage or displacement of artifacts due to the force of the water and debris (Rockman et al. 2016:22).

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[15] DiRi-116 is a Borden number. A Borden number is an archaeological numbering system by which heritage sites are named a unique identifier throughout Canada.

Table 3. Potential effects and impacts of climate change on heritage sites.

Climate effect	Heritage sites	Buildings and structures
Precipitation		
Precipitation pattern changes[16] Extreme weather Severe coastal storm surge Flooding Prolonged wet periods Altered water table, ground saturation, or groundwater Prolonged dry periods Ocean acidification Acid rain Increase in wildfire	Erosion Physical damage due to response to landslide or flood risk (e.g., cleanup and repair activities, dredging, storm and drainage system upgrades, construction of flood management such as dykes and berms) Loss or change in habitat or species Loss of vegetation and trees (e.g., cedar, lodgepole pine) Increased biological growth and disturbance from cryoturbation Fluctuation of moisture levels may increase decay of organic materials Deterioration of water quality Damage to underwater sites from change in salinity, ocean temperature, pH, water movement, dissolved oxygen Drought or reduced humidity could damage or destroy wet site materials, cause loss of stratigraphic integrity (e.g., soil cracking and heave), and exposes sites to damage from UV, looting, weathering Destabilization of sites (e.g., erosion, landslides) Displacement of artifacts due to high water flows or debris Loss of stratigraphic integrity due to drought Change in soil chemistry and pH	Erosion Landslide, flooding, and emergency response and cleanup activities Deposition and reaction of pollutants (e.g., acid degrades materials such as stone surface, metal, timber concrete, mortar, brick) Increased exposure to damp Desertification could lead to erosion, weathering, and abandonment of buildings Increased use (e.g., recreation activities) Thermal damage from wildfires (e.g., combusting/burning, and sooting/soiling) Physical damage from fire suppression, rehabilitation, mitigation, looting/vandalism Intangible impacts to aesthetics, sense of place

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[16] Precipitation pattern change is caused when temperatures rise, and more moisture evaporates from the earth into the atmosphere. This is associated with an increase in heavy rain or snowfall. However, precipitation will not be equal across the province. Some areas may get less precipitation, and some may get more as increased temperatures will also cause a shift in air and ocean currents which alter weather patterns (Daust 2013:3-4).

Climate effect	Heritage sites	Buildings and structures
	Thermal damage from wildfires (e.g., combusting/burning, breaking, cracking, crazing, spalling, pot-lidding, melting, smudging, and sooting/ soiling) Post fire damage (e.g., erosion, deflation) Physical damage from fire suppression, rehabilitation, mitigation, looting/vandalism Increased use (e.g., recreation activities) due to warmer temperatures throughout the year	
Temperature		
Increased annual temperatures Reduction in freeze thaw events Changes to moisture Changes in growing season and shifting bio-geoclimatic zone Increase in invasive species and pests Loss of forest ecosystems: Melt or loss of glaciers, ice patches, and permafrost	Physical damage/disturbance on archaeological deposits due to increased root penetration Accelerated rate of decay of organic materials from increased microbial and fungal activity Ground heave Changes in land use (e.g., farming, residential/commercial development) Loss or change in habitat or species Increase in growing season Destabilization, deflation, and erosion	Exposure to UV radiation, or stronger radiation degrades some materials and is associated with weathering Damage and degradation from wet/dry and freeze/thaw cycles Accelerated rate of decay of organic materials from increased microbial and fungal activity
Coastal Sensitivity		
Sea-level rise Warming oceans Extreme weather	Salinization of soils and water table Flooding Destabilization and erosion Limitation of access due to submersion Exposure of sites	Erosion Saltwater intrusion and damage Storm damage

Climate effect	Heritage sites	Buildings and structures
	Physical damage due to response rising sea levels (e.g., dredging, storm drain upgrades, upgrades to drainage systems, construction of flood management such as dykes and berms) Changes in land use and population movement Tree throws	
Wind		
Distribution of fine particulate matter Transportation of salts Wind driven sand Driving rain Storm surge Increased wave heights	Soiling or blackening of features (e.g., petroglyphs, pictographs) Erosion of soil cover and deflation of archaeological deposits Accumulation of wind-blown sediments Erosion or abrasion of pictographs and petroglyphs Physical damage from tree throws	Soiling or blackening of built structures Particulates may contain chemicals that degrade materials such as stone Particulates may form a crust or corrode certain materials Erosion or abrasion of built structures or features Water saturation

Adapted from: Augustin 2007:25; Boethius et al. 2020:2,10-19; Daly 2011:300; Hollesen et al. 2018:577-579; Kibblewhite et al. 2015:250-251; Rockman et al. 2016:21-24; Ryan et al. 2012:11-12; Sabbioni et al. 2008:10-11; Sesana et al. 2021:8-10; Smith and ICLEI Canada 2020:10; Hamilton et al. 2009:11-26, 217-218; Wright 2016:259-264.

Studies outside British Columbia indicate that drought and lower precipitation can negatively impact archaeological sites, causing the loss of stratigraphic integrity by desertification or soil cracking, vegetation loss, wetting and drying of waterlogged sites in wetland areas, or the exposure of submerged sites because of low water levels along rivers and lakes (Augustin 2007:25; Daly 2011:296; Rockman et al. 2016:22; Smith and ICLEI Canada 2020:10). Exposed sites are more vulnerable to wind, fire, and ultraviolet light (Rockman et al. 2016:22). Once soils dry and crack, oxygen penetrates deeper, causing increased microbial activity, altering stratigraphy, breaking down organic artifacts, or oxidizing metals (Daly 2011:296). Desertification may also lead to site erosion, weathering, or possibly abandonment (Augustin 2007:25; Boethius et al. 2020:12-15). Abandoned heritage buildings that require maintenance could fall to ruin over time.

Several studies outside of the study area have raised concerns that sites preserved in anaerobic environments, such as wetlands and bogs, are most susceptible to climate change (Daly 2011:296; Howard et al. 2005:410). Microorganisms that help support anaerobic site conditions, which preserve archaeological deposits, are sensitive to fluctuations in their environment, such as transferring of water from another waterbody or increasing temperatures (Daly 2011:296; Howard et al. 2005:411). Studies in the United Kingdom and Sweden have shown that drier summers and a decrease in groundwater levels have caused artifact damage or destruction through variations in soil chemistry, oxidization, pH, and soil shrinkage (Boethius et al. 2020:5,17-19; Cassar 2005:26; Daly 2011:296; Howard et al. 2005:410-411; Kincey et al. 2008:115).

Shifts in seasons, such as longer growth seasons, could damage sites due to an increase in the number of invasive plant species and pests and changes in land use, such as farm practices (Parker 2017:18; Rockman et al. 2016:21). A longer growing season could allow for excessive plant grown reducing visibility and limiting site access for future study by reducing the length of the archaeological field season and reduce site visibility (Matthiesen et al. 2020:142,145; Rockman et al. 2016:21). Biological shifts such as vegetation and forest cover could also disturb heritage sites. Changes in vegetation coverage could impact both surface and subsurface site types due to bioturbation and potentially alterations in soil, such as moisture, acidity, and microbial levels (Hollesen et al. 2017:1186; Matthiesen et al. 2020:142; Rockman et al. 2016:21). Non-native species of animals or animals adapting to alterations in environmental conditions could also physically alter sites (Rockman et al. 2016:21). An increase in pests or the introduction of invasive species may cause physical damage to sites (Augustin 2007:25; Rockman et al. 2016:21). Sites may lose their vertical and horizontal integrity due to the increased burrowing of animals (Rockman et al. 2016:21). Site integrity might be diminished if features are modified or destroyed by invasive animals or pests harming organic artifacts (e.g., shipworm burrowing into wrecks, beetles killing culturally modified trees [CMTs]). Some invasive plants can damage built structures and may flourish in changed climatic conditions (e.g., Japanese knotweed) (Rockman et al. 2016:21).

Potential damage to underwater and coastal sites from a change in primary factors needed for preservation include salinity, ocean temperature, pH, water movement, dissolved oxygen, or sea salt chlorides in ocean water, and physical impacts from storm surge (Augustin 2007:25; Wright 2016:259-263). Much like terrestrial sites, the preservation of submerged sites is complex (Wright 2016:260). Without amenable conditions, organic materials would deteriorate, and metals may corrode (Wright 2016:260). Warmer temperatures may also increase different species of animals and plants that damage underwater sites. Once they have established a colony, zebra and quagga mussels may damage submerged sites in British Columbia’s waters (Province of British Columbia 2015:8; Wright 2016:261). The zebra mussel is associated with an increase in the growth of bacteria that degrades artifacts (Wright 2016:261) and contributes to ocean acidification that can corrode metal artifacts (Boethius et al. 2020:2; Wright 2016:262).

Predicted changes in precipitation and temperature patterns could lead to shoreline erosion, increased rate of decomposition of organic materials, and damage to sites from storm effects (Perry and Falzon 2014:10). In their study of climate change impacts and recommendations for adaptation strategies for the British Columbia coastline, Whitney et al. (2020:719) observed that storm events and king tides have increased in intensity and frequency. Such storms have caused sites near Metlakatla and Prince Rupert to erode and expose artifacts (Whitney et al. 2020:719). Activities related to disaster response to storms, flooding, coastal erosion, and landslides could damage sites. (Rockman et al. 2016:24). In addition, efforts to reduce or minimize the effects of a disaster, such as installing engineering systems to protect shorelines from flooding, may also cause damage to sites.

Warmer temperatures and precipitation patterns can also lead to longer growing seasons and increased presence and abundance of invasive plant species and pests (Parker 2017:18). This can mean tree species such as lodgepole pine in the Interior Plateau and Western redcedar in the Coastal Mountains and Islands regions can no longer thrive. One of the most common archaeological features in this region is CMTs[17]. These living heritage feature are evidence of pre-historic forest use but have a limited life expectancy (Eldridge 1997:1). Culturally modified lodgepole pine trees are vulnerable to pests and may not adapt to changes in temperature and precipitation. Climate change may result in premature death and degradation of these living features. Other heritage sites indirectly impacted by the MPB outbreak include cultural depressions, trails, habitation features, burials, and surface and subsurface lithics, since all could be damaged by windfall or MBP management activities such as timber harvesting. In the late 1990s and early 2000s, changes in precipitation and temperature led to one of Canada’s largest mountain pine beetle epidemics, which damaged or killed millions of hectares of lodgepole pine forests (British Columbia Ministry of Community Development n.d.; BCMoE 2016:42; Province of British Columbia 2020c).

Severe wildfires may threaten the preservation of heritage sites (Brown et al., 2017:615). High temperatures can damage stone, bone, organic, metal, and ceramic materials (Deal 2012:98; Oster et al. 2012:147; Stefanyshen 2019:48). Heat and carbon from fires can also impact the ability to conduct palaeobotanical, protein residue, dendrochronological, DNA, and radiocarbon analysis (Oster et al. 2012:148-150). Wildfires could chemically or physically damage or destroy archaeological and historical sites (Friggens et al. 2021:2; Rockman et al. 2016:21; Ryan et al. 2012:12). Direct effects to lithic artifacts from fire include oxidation/colour change, pot-lidding, spalling, smudging, sooting/soiling, crazing, fracturing, or burning (Langley 2001:38; Rockman et al. 2016:21; Ryan et al. 2012:13). Sites that have been burned may be more susceptible to erosion, weathering, deflation, and flooding (Rockman et al. 2016:21; Ryan et al. 2012:12). Activities related to fire suppression (i.e., use of fire-retardant chemicals, constructing access and fire guards) and repairing infrastructure may injure or destroy heritage sites (Deal 2012:108). In addition, areas burned by wildfires present an

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increased risk of soil erosion, debris flows, flooding, and landslides (Hope et al. 2015:1), especially after high or sustained precipitation events.

As much as fire destroys and damages heritage sites, it also clears away ground cover, exposing artifacts and surface features (Deal 2012:98; Hammond 2018; Parks Canada 2019). Archaeologists may thus be able to record more sites with ground exposures than with subsurface testing alone (Deal 2012:98). When there is little to no vegetation, a larger area can be surveyed in less time, reducing assessment costs (Deal 2012:98). It would be easier to detect landforms that are likely to contain subsurface deposits, which would improve the quality of the assessment. Also, archaeologists typically overlook these areas as having a low potential for finding heritage sites (e.g., sloped terrain) could more readily be included in the sampling area, improving survey results. However, artifacts exposed on the surface are more visible to the public, making them susceptible to unauthorized collection (Rockman et al. 2016:21).

Unfortunately, few studies have identified the types of sites that would be sensitive to damage or evaluate the long-term effects of wildfires on heritage sites, so an understanding of the full impact these events may have in the future is not entirely understood (Sinsky 2020:16). In the United States, archaeologists working in Kaibab National Forest in Arizona investigated the effects wildfires have had on archaeological sites since the early 2000s (Hangan 2008:46). Their study results were used to develop strategies for the Kaibab National Forest heritage managers to reduce impacts of wildfires on sites located in this area (Hangan 2008:46).

2.5.2. Temperature

Temperature changes influence the number and intensity of wildfires, alter the timing and duration of seasons and biological cycles, cause species and vegetation shifts, increase invasive pests, the rate of decay of organic materials (e.g., wood, leather, bone), the frequency of wet/dry and freeze/thaw cycles, permafrost melt, and humidity, and cause a change in seasonality (Friggens et al. 2021:1; Hollesen et al. 2018:577-579; Rockman et al. 2016:21-24). A temperature change can also affect the number and duration of extreme weather events such as heatwaves and snowstorms (Augustin 2007:25). Extreme heat and cold weather events may stress historic buildings and cause thermal damage to exteriors (Augustin 2007:25). Freeze-thaw, wet frost, and ice storms may cause physical damage to sites such as spalling or artifact migration (Augustin 2007:25). Concomitantly, modifying historic buildings to withstand extreme heat or cold could damage or destroy the infrastructure (Augustin 2007:25).

British Columbia has environments where anoxic conditions protect heritage sites due to the presence of high moisture levels and frozen ground, such as permafrost, ice patches, and glaciers. Studies in Greenland on sites in permafrost indicate a predicted change in temperature of 2.2 to 5.2°C could impact up to 40% of organic preservation (Hollesen et al. 2017:1186). Even if soils (e.g., permafrost) are kept moist, the rise in temperature leads to breakdown of the organic site remains due to an increase in oxygen levels from microbial heat production (Boethius et al. 2020:19; Fenger-Neilsen et al. 2020:1284; Hollesen et al. 2017:1179). For instance, buried organic materials, such as wood and bone, deteriorate faster in places where temperatures are higher and soil moisture levels lower (Boethius et al. 2020:19; Hollesen et al. 2017:1175; Smith and ICLEI Canada 2020:10). Similarly, conditions where organic site remains are exposed to higher oxygen levels due to thawing or lowering of water tables, could negatively impact heritage sites with organic components (Daly 2011:297; Hollesen et al. 2018:574-575,579). Freeze and thaw also cause ground heave and cracking, further disturbing the subsurface composition of sites (Daly 2011:297).

2.5.3. Coastal Sensitivity

Sea-level rise events such as inundation, increased flooding, increased coastal erosion, a higher water table, and increased severity and frequency of storms may negatively affect heritage sites (Augustin 2007:25; Daly 2011:296; Rockman et al. 2016:23). Organic artifacts or features are susceptible to damage by increased flooding or change in pH levels. Ocean acidification would have an impact on the preservation of shell bearing sites. Increased flooding and sea-level rise could mean sites in coastal areas become inundated and restrict access to sites for salvage or research (Rockman et al. 2016:23-24). Erosion exposes artifacts and makes sites more susceptible to unauthorized artifact collection (Carmichael et al. 2017a:241-242; Rockman et al. 2016:23; Wright 2016:258). Sites may erode or be undercut due to water encroachment, increased downstream currents, wave action, or wetting and drying (Rockman et al. 2016:23; Smith and ICLEI Canada 2020:10). Increased frequency and severity of storms could erode or destroy coastal sites (Augustin 2007:25; Carmichael et al. 2017b:232; Daly 2011:296; Rockman et al. 2016:23). A high or fluctuating water table may also damage artifacts, stratigraphy, and features, as well as restrict access to researchers (Rockman et al. 2016:23). Each of the sea-level rise events in Table 1 could act independently but more often would work in concert with other climate events, sometimes worsening impacts.

Sea-level rise, in combination with other climate change events may lead to saltwater intrusion[18], pollution, ocean acidification, extreme weather, and increased land development[19], impacting sites in several ways (Anderson et al. 2017:2; Rockman et al. 2016:24; St. Amand et al. 2020:1762; Wright 2016:258-259). It can make sites vulnerable to damage and increase the rate of artifact deterioration, altering their long-term stability (Augustin 2007:25; Rockman et al. 2016:24). An increase in groundwater and flooding can damage built structures. Extreme weather events, such as more intense storm surges, wave action, winds, and heavy precipitation, could cause accretion or erosion of sediments, exposing artifacts and features (Rockman et al. 2016:24; Wright 2016:259-260). As a result, site context could be affected by shifting artifacts or deflating features. The movement of sediment or changes in vegetation cover caused by extreme weather could destabilize or damage coastal, nearshore, underwater, or intertidal sites (Rockman et al. 2016:24; Wright 2016:258).

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[18] Salt intrusion or the introduction of water with a different chemical makeup.

[19] Relocating utilities, infrastructure, and buildings in response to sea-level rise may increase land development. Climate change-related events such as landslides, floods, or wildfires can cause people to relocate to previously undeveloped areas (Rockman et al. 2016:24).

Ironically, activities related to cleaning up after extreme weather events could also damage sites (Rockman et al. 2016:24). Other responses to sea-level rise that could affect heritage include anthropogenic responses such as land development and engineering solutions (Anderson et al. 2017:2; Howard et al. 2005:412). Due to coastal instability or submersion, coastal areas become more vulnerable, and land-use shifts inland. Thus, inland sites not directly impacted by sea-level rise may be damaged by development associated with resettlement (St. Amand et al. 2020:1761). Engineering solutions to protect communities and vital services could include upgrades to coastal defenses (e.g., dikes), drainage, power and communication lines, and transportation routes (Rockman et al. 2016:24). Building and maintaining these defenses could further affect coastal sites.

2.5.4. Wind

Wind and air currents transport two types of air pollutants through the atmosphere that can harm heritage objects and sites: corrosive gases[20] and fine particulate matter[21] (Hamilton et al. 2009:1,11-26). When sulphur dioxide and nitrogen oxide gases enter the atmosphere, they mix with water and return to earth as acid rain (Pigott and Hume 2009:206). Increased carbon dioxide released into the atmosphere mainly by burning fossil fuels is associated with ocean acidification (Hamilton et al. 2009:1). Acid rain and ocean acidification lead to corrosion of metal, timber, glass, stone, concrete, brick, and mortar, and to the blackening of buildings or features such as petroglyphs or pictographs (Augustin 2007:25; Boethius et al. 2020:2; Kibblewhite et al. 2015:250; Rockman et al. 2016:24; Hamilton et al. 2009:11-26, 217-218). Pollution from fine particulate matter blackens site features (Hamilton et al. 2009:2). Acidic conditions can also degrade bones, teeth, shells, and other organic materials (Boethius et al. 2020:2,19; Kibblewhite et al. 2015:250; Rockman et al. 2016:24). These particulates may contain acidic chemicals that, when exposed to water, corrode materials that could

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[20] 'Some air pollutants exist in the gaseous phase at ambient temperatures (e.g., NO^2, SO^2, and O^3). The definition of particulate includes both the liquid and solid forms of matter' (Watt et al. 2009:10). Sulphur dioxide (SO^2) and nitrogen dioxide (NO2) cause acidification.

[21] "Airborne particulate matter includes any material that can be transported through the atmosphere by wind and air movements including particulate matter up to 1 mm in diameter, although most particles in the ambient atmosphere are significantly smaller than this" (Watt et al. 2009:10).

have significant impacts on sites especially shell bearing sites along the coast of British Columbia (Boethius 2020:2; Hamilton et al. 2009:1).

Driving rain and storm surges may cause CMTs to become less wind firm and possibly topple (Rockman et al. 2016:21). Winds carry sand and other particulates that can bury sites or erode buildings and other features such as pictographs or petroglyphs (Rockman et al. 2016:24). Winds also increase wave heights causing increased erosion and deflation of sites located along the margins of water bodies.

2.6. Chapter Summary

There is growing evidence that the rate of climate change has accelerated in the last century. From this, we can expect ongoing changes in sea-level, temperature, and precipitation, and an increase in extreme weather events, although the type, frequency, and duration of these is uncertain. These changes have already had and will continue to have significant impacts, including on heritage. In British Columbia, over the past thirty years, approximately 18.1 million hectares of pine trees were affected by MPB and over 3 million hectares of forest burned in wildfires, with an unknown number of sites being disturbed or destroyed. Changes in precipitation will likely continue to cause erosion and displacement of artifacts, destruction of wet sites, and damage from forest fires and acid rain. Temperature changes may cause site damage through freeze/thaw events and the melting of glaciers and ice patches, and less directly through related changes in vegetation and growing season. A corresponding rise in sea levels may lead to site exposure or submersion with associated destruction or lack of access to sites. Increased wind may also cause damage, especially to petroglyphs, pictographs, and CMTs. Less obviously, damage and destruction of sites can also be expected to result from responses to climate change, including forest fire suppression and construction related to changes in land use.

Chapter 3.

Research Methods

In this chapter I describe how I achieved my study objectives and answered my research questions. Specifically, my objective was to obtain an overview of the risks to heritage sites from climate change within British Columbia using GIS tools to compare known sites with predictive climate models. To characterize the nature of impacts and to quantify the affected sites, I addressed four questions:

1. How many heritage sites have been predicted to be affected by climate change (e.g., temperature, precipitation, coastal sensitivity) in British Columbia?
2. Will changes in the climate affect heritage sites?
3. What benefit is there in using GIS software to overlay known sites, predictive climate change models, and past climate change event polygons to identify threats and vulnerable heritage sites?
4. Can anything be done to improve climate change forecasting and management of the impacts on heritage sites?

To identify the number of heritage sites modelled to be affected by climate change in British Columbia, I used the open-sourced Quantum GIS software application (version 3.14) to compare the models and registered site data. This produced a series of attribute tables and corresponding spatial layers that indicate which sites intersect with the various climate threats and the degree of impact severity as determined by the modelled severity rating. In addition, information on past climate change events affecting sites was gathered by repeating the same intersection with datasets for wildfires and MPB infestations. I examined the attribute tables and spatial layers for modelled and past climate change' in order to understand what impact climate change has on heritage sites in the province.

3.1. Data Collection

To collect geospatial datasets for British Columbia of registered heritage sites, climate change modelling, and past climate change events. I used pre-existing datasets provided by the Governments of British Columbia and Canada. Global warming models, available with geospatial data that could be compared to site locations, were restricted to coastal sensitivity, temperature, and precipitation predictions. The climate change data are publicly available, whereas the provincial heritage data require special permission to access. Based on the data's quality, the site dataset's useability varied. Here I explain data limitations and how the information was refined or omitted from the analysis.

3.1.1. Coastal Sensitivity Climate Change Data

I employed version 2.5.6 of publicly available CanCoast coastal sensitivity model for the analysis (Government of Canada 2020a). This model uses the representative concentration pathway (RCP) emission scenario 8.5, or the highest global emission scenario. The dataset incorporated into the model included climate and environmental variables for geology, slope, elevation, tides, ground ice, wave height, and sea-level. The model output identified coastal areas potentially to be impacted by physical changes such as destabilization, flooding, erosion, or sediment migration between 2006 and 2099 (Manson et al. 2019:2). The numerical scale determined by the CanCoast modelling team for indices, including sea-level change, decadal mean wavelength, ground ice, material[22], slope, and tidal range, was used for the analysis of coastal sensitivity (Manson et al. 2019:3). For the analysis, I utilized the 2090 and 2000 coastal sensitivity indices.

The model employed general data and indices to compare the degree of physical change due to climate variability between the early and late 21st century (Manson et al. 2019:13). Generalized indices were calculated using µ-statistics. For the indices to be mapped, they were assigned sensitivity scores (Manson et al. 2019:13). A total score value that was less than -500 meant the coastal type had very low sensitivity; a score between -499 and -150 was low, -149 to 150 was relatively moderate, 150 to 500 was high, and a score greater than 500 meant the coastal sensitivity type was very high (Manson et al. 2019:16). The identical sensitivity scores used in the CanCoast model were applied to the intersection data to determine the potential sensitivity of sites to coastal change. The CanCoast model geometry consisted of single polyline that traced

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[22] "Material" includes intrusive, metamorphic, volcanic, sedimentary rocks, bedrock, sand, rubble, gravel, silt, clay, and peat (Manson et al. 2019:3).

the existing coastline. Polygons of heritage sites, rather than point data, were intersected with the polyline data with QGIS software so the intersections would be more accurate.

3.1.2. Temperature and Precipitation Scenario Climate Change Data

In October of 2020, I contacted the Canadian Centre for Climate Services (CCCS) to request climate change prediction modelling datasets for British Columbia. I was provided with links to publicly available modelling datasets for change in temperature, precipitation, and coastal sensitivity scenarios. I accessed statistically downscaled23 climate scenarios for precipitation and temperature datasets using the Government of Canada's climate change extraction tool (Government of Canada 2020b). The variables selected for the modelling data download were "total precipitation," "minimum temperature", and "maximum temperature." The measurement scale used in the analysis of Minimum and Maximum Temperature was in degrees Celsius (°C), and that for Total Precipitation in millimetres (mm).

Other variables chosen for the model download included an RCP emission scenario of 8.5. This was chosen to pick up the maximum number of heritage sites that may be impacted and to match the RCP scenario used by the CanCoast model developers. I selected the "75th percentile" variable, meaning that 75% of the models used indicated the same or less warming results. I also selected an "annual time interval" for temperature and precipitation, and "actual" rather than "anomaly" values. For total precipitation, time intervals for the summer (June to August) and winter (December to February) were selected because these times of year would have the most change, with precipitation being lower in the summer and higher in the winter. The dataset format downloaded was Tag Image Files (TIF). The CCCS modelled data were available for the years 2006 to 2100. The years 2020, 2050, and 2100 were chosen for each variable to compare and analyze.

The model layer images for precipitation and temperature consisted of thousands of square pixels. Each pixel was assigned a model value and represented a 6km x 6km area on the ground. Rather than shapefile polygons, point data were created from the

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[23] Statistical downscaling is a method used to translate large-scale Canada wide climate change model data into smaller spatial scales (e.g., a province or municipality) that can be used more effectively by local planners (Pacific Climate Impacts Consortium n.d.).

coordinate locations for heritage sites included in the Excel files provided by the Archaeology Branch and used for the intersection. This eliminated the issue of long linear sites (e.g., trails) having more than one climate change event value if the site overlapped multiple pixels. The heritage point data were intersected with the total precipitation, minimum temperature, and maximum temperature area model data for the years 2020, 2050, and 2100.

3.1.3. Historical Global Warming Data

Changes in precipitation and temperature patterns have significantly impacted heritage sites in the past, but these impacts have been difficult to measure. Recent studies in British Columbia have linked climate changes (warmer temperatures and lower precipitation) to an outbreak of MPBs in the late 1990s and early 2000s, and more recently to the severity and size of wildfires (Burleigh et al. 2014:3; Carroll et al. 2003:225-227; Meyn et al. 2009:986-987; Nikiforuk 2011:60-62). Because the number of sites affected by these events is not consistently recorded on site forms, calculating the number of sites affected was difficult. Therefore, the method I used to determine an approximate number of sites potentially impacted by wildfires and pest infestation was to compare known locations of heritage site locations with wildfires and pest infestation geospatial data.

Wildfires and MPB datasets used for the analysis were publicly available on iMapBC and the British Columbia Data Catalogue (British Columbia MFLNRORD 2011a, 2011b). These consist of polygon shapefiles indicating the areas of impact for the province. The wildfires and pest infestation datasets include numerous polygons with metadata attached indicating the size of the area, year, and impact type. Data tables showing the number of sites impacted and the extent of climate change impacts were generated by intersecting site location point data with wildfire data and MPB infestation data. CMT sites were isolated from other datasets and compared separately due to their vulnerability to wildfires and MPB. Results were reviewed in Excel using a pivot table and histogram to see if these correlated with reported climate change in the province (Allan et al. 2003; Government of Canada 2019; Kirchmeier-Young et al. 2019; Lettrari 2017:7). The data analysis determined the number of CMT sites that may have been adversely affected by wildfires or the mountain pine beetle in British Columbia.

3.1.4. Provincial Heritage Site Information

I submitted an Archaeological Information Request application to the British Columbia Archaeology Branch to obtain data on all archaeological, historical, and traditional use sites recorded in the province. Records for 58,113 heritage sites were delivered to me on October 26, 2020. Detailed site information was provided in Excel spreadsheet and shapefile formats. Data used in the analysis included site location geometry or coordinate data, names, typology, and condition. The site name was used as the unique identifier value. Site geometry was provided in three formats: shapefile polygons, geographic coordinates (latitude and longitude), and Universal Transverse Mercator coordinates (eastings and northings). The projection used was North American Datum 1983 (NAD 83/BC Albers). The coordinate data and unique identifier were input into GIS to create a vector data layer for both site point and sites areas or polygons. These layers were then converted into raster data so they could be compared with the climate model datasets. The comparison produced output tables and spatial layers. Information in the output tables indicated the number of sites and scale of modelled global warming impact. A quantitative analysis of the output tables was conducted using pivot tables and histograms to determine the severity of damage and the number and type of sites impacted by each of the climate change event variables.

The reliability of the site coordinates used in the climate change dataset comparison varied since many sites were recorded prior to Global Positioning System (GPS) being made available to the public in 1983 or when the signal become more accurate and reliable in 2000 (Ohio University 2021). Which meant site coordinates used in this analysis were not always accurate and the precision of the location coordinates was unknown. The dataset was analyzed only after removing obvious outliers where sites fell outside the boundaries of British Columbia, or the location geometry was missing. All invalid site geometry was selected in QGIS using the expressions “NOT invalid($geometry)” and “SHAPE_AREA is 0.” Subsequently, 867 site polygons were removed from the dataset due to invalid geometry, of which 38 site polygons had invalid geometry and 829 had a shape area and shape length of zero or geometry was absent. The data table was sorted by location to find missing site geometry. Any sites without geometry information were removed from the analysis since they could not be compared to the model data. This left 57,246 sites for the analysis for the coastal sensitivity model. An additional 1,206 were excluded for the temperature and precipitation climate change data comparison because they were not covered by the climate change model raster data. The temperature and precipitation data were analyzed for 56,040 sites from the Provincial Heritage registry. The data were then plotted using QGIS software.

3.2. Dataset Analysis

I conducted a quantitative analysis to assess the potential for heritage sites to be impacted by modelled global warming scenarios. For this analysis, summaries were obtained of the number of sites that occur on various climate change model scenarios. The analysis used two input data themes (site location and climate change prediction) and produced a table as the output (sites listed against climate change prediction type) (Wheatly and Gillings 2002:80). CanCoast and CCCS model layers included different scenarios for predicted future change in precipitation, temperature, and coastal sensitivity over various time steps (e.g., coastal sensitivity 2090s, minimum temperature 2020, maximum temperature 2100). Known wildfires and MPB event geometries were examined to provide information on past climate change impact. Due to the high volume of geometries in each dataset and multiple global warming scenarios, I used QGIS software for the analysis.

The locations of registered heritage sites were “intersected” with future climate model prediction and past global warming event layers. This term is used in the analysis of geographic data as shorthand for a specific process that involves the use of an algorithm to join different datasets or mapping layers using spatial criteria (Clarke 1990:156-164). The intersected layers were in the same mapping projection and had at least one location point in common. When the query was run, the common points were joined. The algorithm output was a new attribute table and correlated spatial layer. The resulting intersection output table and spatial layer included various model event scenarios and timesteps for each heritage site. The output data were examined to discern the severity of impact from individual and cumulative climate change events. A summary of information was presented using figures, tables, and histograms. The figures were produced to depict higher level data overlap. Tables and histograms illustrated the overlap between sites and modelled climate change layers.

3.3. Limitations

Detailed background information is needed to determine if modelled climate change could impact heritage sites in British Columbia. My analysis identified two gaps related to inaccuracies in the datasets used: sites not being plotted correctly, and model data not being high enough resolution. Therefore, the limitations described below should be kept in mind when interpreting the study results.

The primary limitation is that the Provincial Heritage Register does not consistently record accurate spatial data for all sites. Before using GPS, many sites were recorded and documented on 1:50,000 scale national topographic system index map sheets or hand-drawn figures. These locations were later digitized and included in the registry. Also, GPS's does not always record sites with good accuracy if overhead obstructions obscure the signal to the satellite (e.g., trees, bridges, buildings). As a result, many sites are mis-plotted. As the model and site comparison only picked up overlapping layers, the reliability of the datasets limited the study's accuracy.

The resolution and expression of the model data are also limitations of this study. The primary constraint of the CanCoast model is the horizontal inland inundation extents were not modelled, thus sites in areas potentially impacted by future climate change (e.g., flood zones, king tides, erosion) were not captured. The resolution of the CCCS models for temperature and precipitation was low (i.e., 6km x 6km pixels). This does not significantly impact a regional assessment of climate threat, but modifications to refine the model output would improve the ability of researchers to quantify impacts on smaller areas or individual sites. Due to time limitations, I did not include how higher resolution models could lead to better prioritize sites with features or artifacts sensitive to changes in moisture or temperature. Not all sites may be impacted in the same way, even if subjected to identical environmental changes. Research on the relationship between future climate conditions and site degradation processes could significantly improve models despite differences in site preservation conditions.

RCP 8.5 is the highest global emission scenario where the assumption is the greenhouse gas emission will increase over time (Wayne 2013:14). Using this model scenario should have captured the maximum number of heritage sites predicted to be affected by climate change. The projection for CanCoast model was set at RCP 8.5 by the developer. I also used this projection for the CCCS models. Employing a more severe projection means my study could be a worst-case scenario forecasting future conditions. This outcome could make my study’s results more alarming than if I had used another model scenario.

My study only examined registered heritage sites. However, large portions of the province have not been inventoried. Obviously sites not yet identified were not included in my analysis. There are models available on the Provincial Heritage Register that calculate archaeological potential, but these were not incorporated into my study as many of them are out of date and do not cover the entire province. These models also predict whether a site will be present rather than the total number of sites that might exist, so comparing them to climate change models would be difficult.

3.4. Chapter Summary

This study brings together three key types of data: climate predictive data associated with the CanCoast coastal sensitivity model and provided by the Canadian Centre for Climate Services; data from historical climate change events; and data on known heritage sites from the British Columbia Provincial Heritage Registry. The research methods used in this study, employing GIS tools to compare known sites with climate prediction models, enabled me to use both quantitative and qualitative analysis to graphically illustrate the potential impacts of climate change on heritage sites in British Columbia, as well as the potential value of GIS to improve predictive capacity and management potential.

Chapter 4.

Results

In this chapter I present the results of comparing climate change models and past global warming event datasets to locations of registered heritage site locations to help answer the research questions. I first discuss the dataset intersection and the number of sites located in areas predicted to be affected by changes in coastal sensitivity, temperature, and precipitation, as well as the severity of the impacts. I then describe the results of the intersection of known sites and risk events for wildfire and MPB to see how many sites may have been affected in the past. I use the total number of sites predicted to be affected to determine if GIS software is beneficial in predicting climate change impacts on vulnerable sites and what can be done to improve these predictions.

4.1. Coastal Sensitivity and Archaeological Site Polygon Dataset Intersection

The modelled coastal sensitivity polyline and heritage site polygon datasets were joined by their attributes to determine where sites overlap with coastline sensitivity data. Heritage sites intersecting with the areas of predicted coastal sensitivity are shown in Figure 1. A total of 57,246 heritage polygons were intersected, and 4,722 sites overlapped the coastal sensitivity model polylines[24]. Figure 2 shows coastal sensitivity scores and the number of sites that overlapped with each of the assigned ratings.

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[24] I used the same polyline location for both the 2000 and 2090 scenarios, but the sensitivity scores along the polylines changed from 2000 to 2090. Some large heritage site polygons intersected with different areas of modelled coastal sensitivity and therefore the total number of sites (i.e., 4,722) is lower than the maximum number of intersections for 2000 (i.e., 6,723) and 2090 (i.e., 6,813).

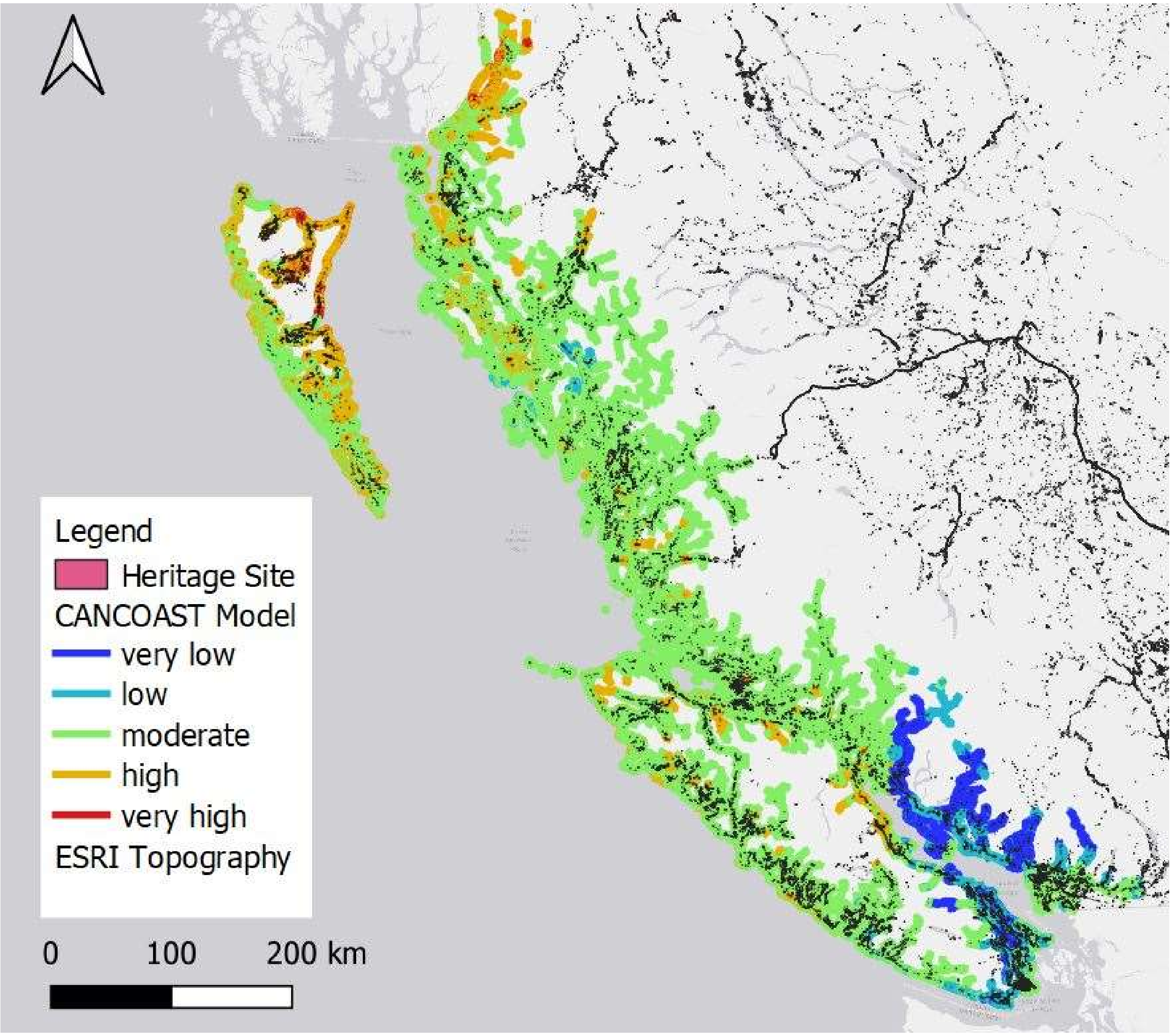

Figure 1. Sites intersected with areas of predicted coastal sensitivity change (2000s to 2090s).

The difference in the number of sites in areas modelled to have a change in coastal sensitivity from the 2000s to the 2090s was determined by comparing the coastal sensitivity scores and corresponding ratings. The Coastal Sensitivity Rating system is based on a numeric score: “very low” (<-500), “low” (501 to -150), “moderate” (-151 to 150), “high” (151 to 500), and “very high” (> 500). The results of this comparison showed that in 2000, sensitivity ratings were “very low” for 1,154 sites,” low” for 605 sites, “moderate” for 2,795 sites, “high” for 163 sites, and “very high” for 6 sites (Figure 2). The 2090 sensitivity scores for 495 sites were very low, 748 sites were low, 2,945 sites were moderate, 512 sites were high, and 23 very high. The 2000s sensitivity scores indicated 63% of sites were in the moderate to very high sensitivity range rather than the very low to low range (Figure 2). For the 2090s, coastal sensitivity scores indicated 74% of sites had moderate to very high coastal sensitivity rather than the very low to low range.

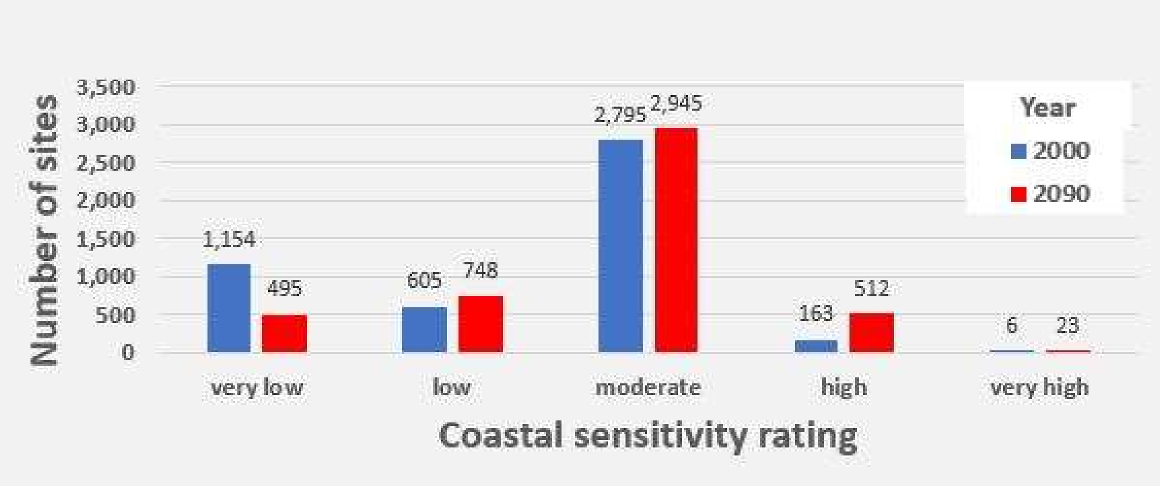

Figure 2. **Difference in the number of heritage sites between the years 2000 and 2090 overlapping with areas modelled coastal sensitivity.**

I calculated the decrease or increase in coastal sensitivity based on the difference between the 2000s and 2090s sensitivity results. The scores and change rankings were the same as the ones used in the CanCoast model. A coastal sensitivity score of zero resulted in a decrease, a score between 1 and 500 resulted in a moderate increase, and a score over 500 resulted in a large increase. For the coastal areas modelled, there were 412 sites or 9% that showed a reduction in coastal change, 3,182 sites or 67% had a moderate rise in coastal change, and 1,128 sites or 24% showed a large increase in coastal change (Figure 3). Overall, by 2090 most sites were in areas of the coastline modelled to have moderate or lower coastal sensitivity ratings. However, the number of sites in areas predicted to have a high or very high coastal sensitivity rating increased.

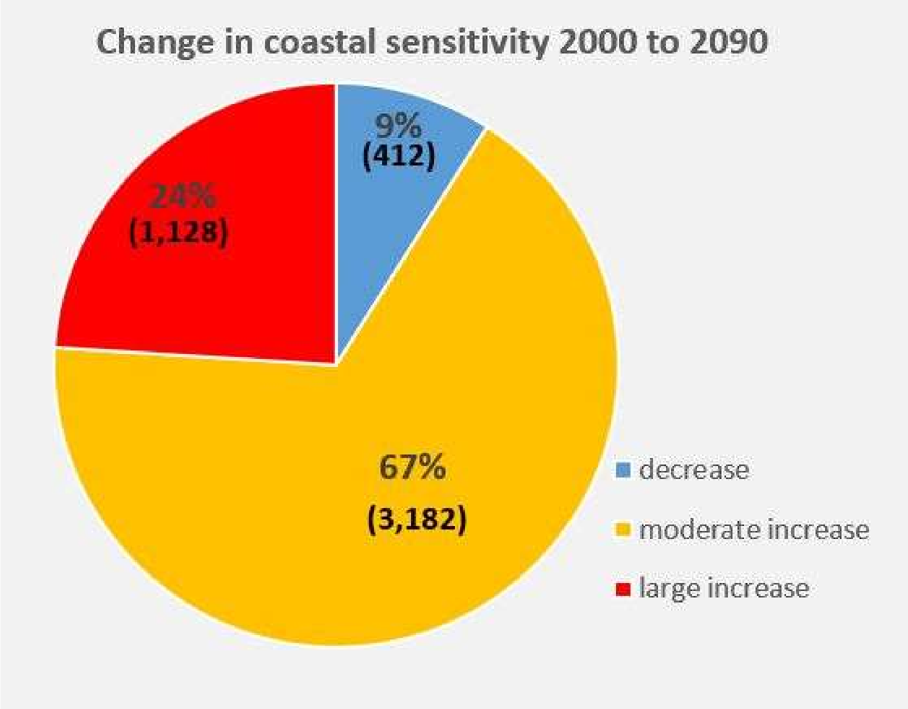

Figure 3. **Percentage of sites with change in modelled coastal sensitivity 2000 to 2090.**

4.2. Climate Change Scenario Dataset Intersections

I calculated scenarios of climate change for the years 2020, 2050, and 2100, using minimum temperature, maximum temperature, and total precipitation. Model data included rasters or pixels that were overlain on heritage locations to calculate the number of sites in each raster cell. Based on the modelled scenario for 2020, I compared whether there could be any change in the number of sites and the degree of temperature or amount of precipitation. Here I present the results of the temperature and precipitation data and model comparisons.

4.2.1. Temperature

The minimum temperature scenario model area overlapped with 53,814 sites for the 2020 dataset, 55,937 for the 2050 dataset, and all 56,040 sites in the 2100 dataset. In the modelled 2020 minimum temperature scenario, 22,401 (40%) heritage sites were in areas with temperatures below 0°C and 33,639 (60%) sites were in areas above 0°C (Figure 4). For 2050, 11,405 (20%) of the same sites were in areas with temperatures below zero and 44,635 sites or 80% were in areas above 0°C. For 2100, there were 119 sites or 0.2% in areas with temperatures below zero and 55,921 sites or 99.8% in areas above 0°C. In addition to fewer sites having below-freezing temperatures over time, the range of minimum temperature also changed. For 2020, sites overlap areas that ranged in temperature from -7 to 9°C, for 2050 -5 to 11°C, and 2100 -1 to 13°C (Figure 5Figure 6). In the modelled 2020, 2050, and 2100 maximum temperature scenarios, all sites experience temperature increase, with none in areas with temperatures below 0°C. For 2020, sites overlapped areas that ranged in maximum temperature from 3 to17°C, for 2050, 5 to 18°C, and for 2100, 8 to 22°C (Figure 7Figure 8).

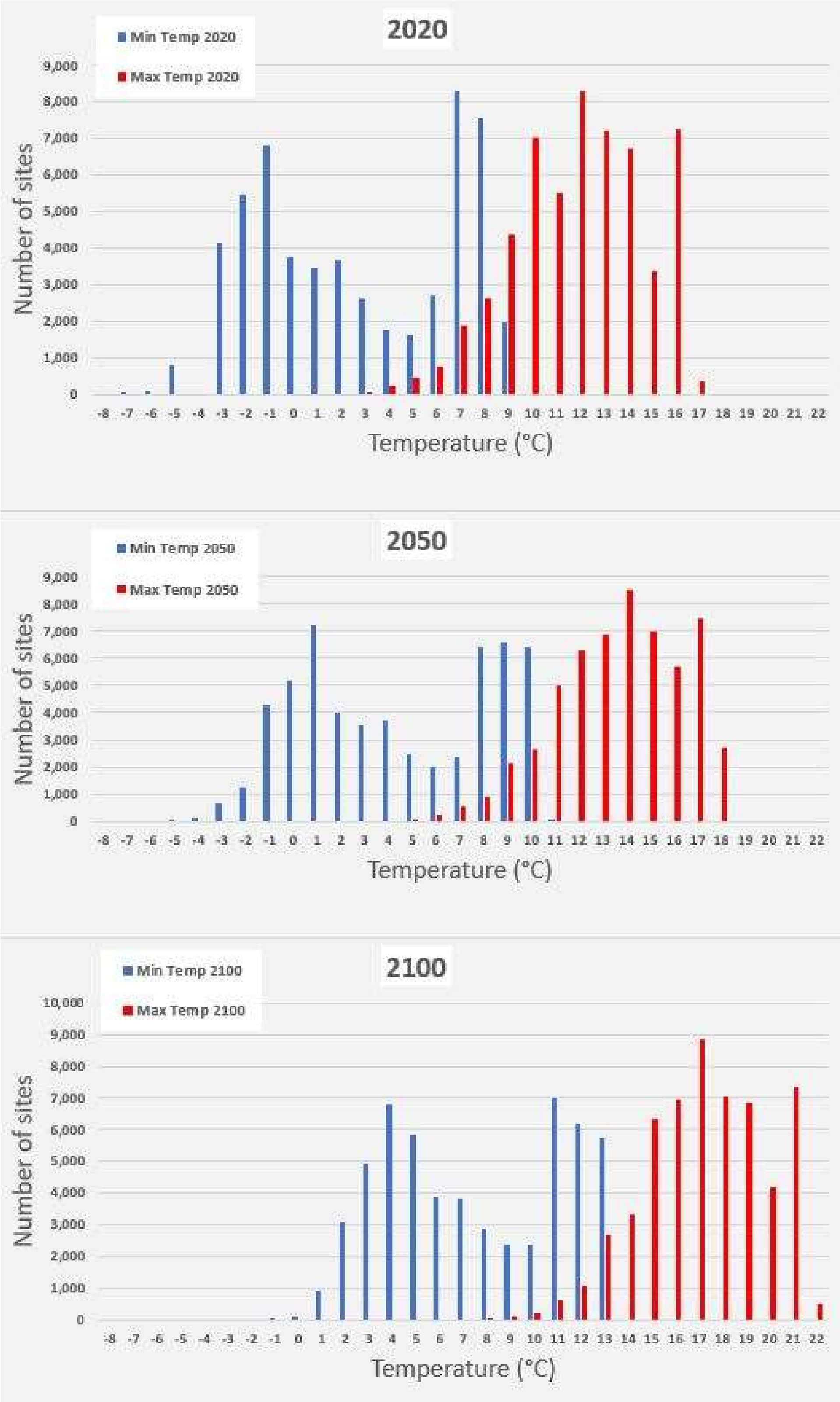

Figure 4. **Number of heritage sites per climate change scenario (2020, 2050, 2100) by temperature.**

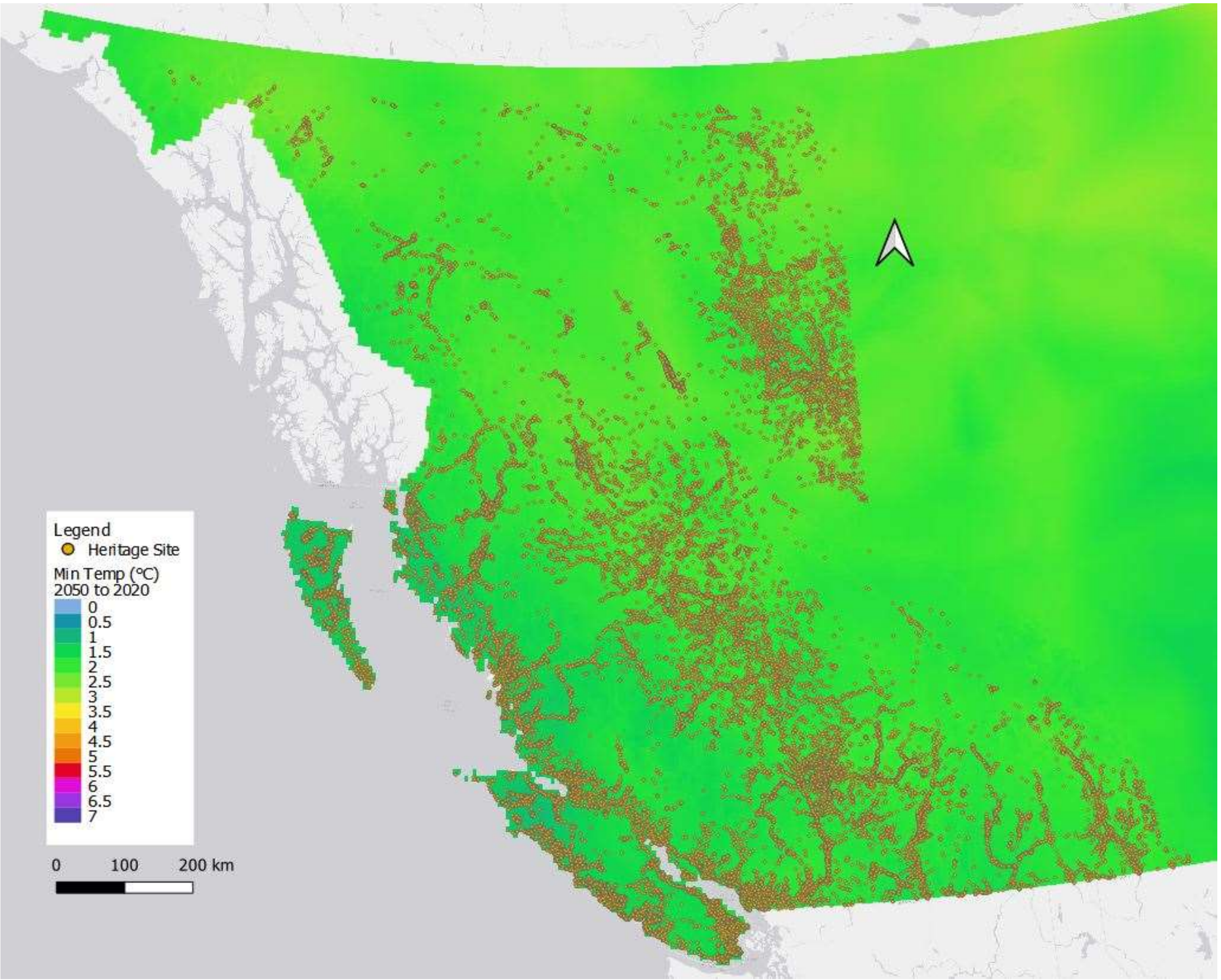

Figure 5. **Minimum temperature (°C) 2020 to 2050.**

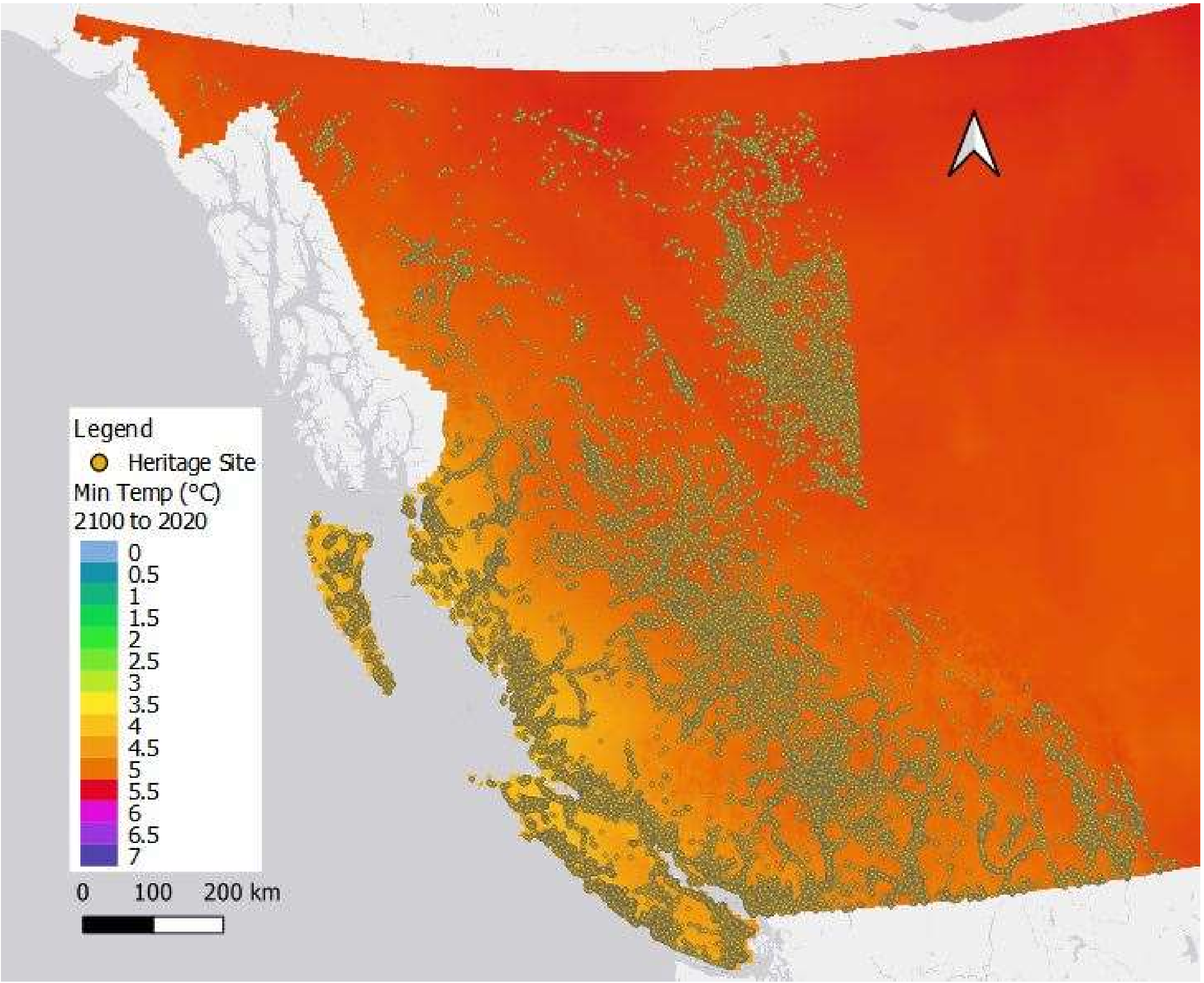

Figure 6. **Minimum temperature (°C) 2020 to 2100.**

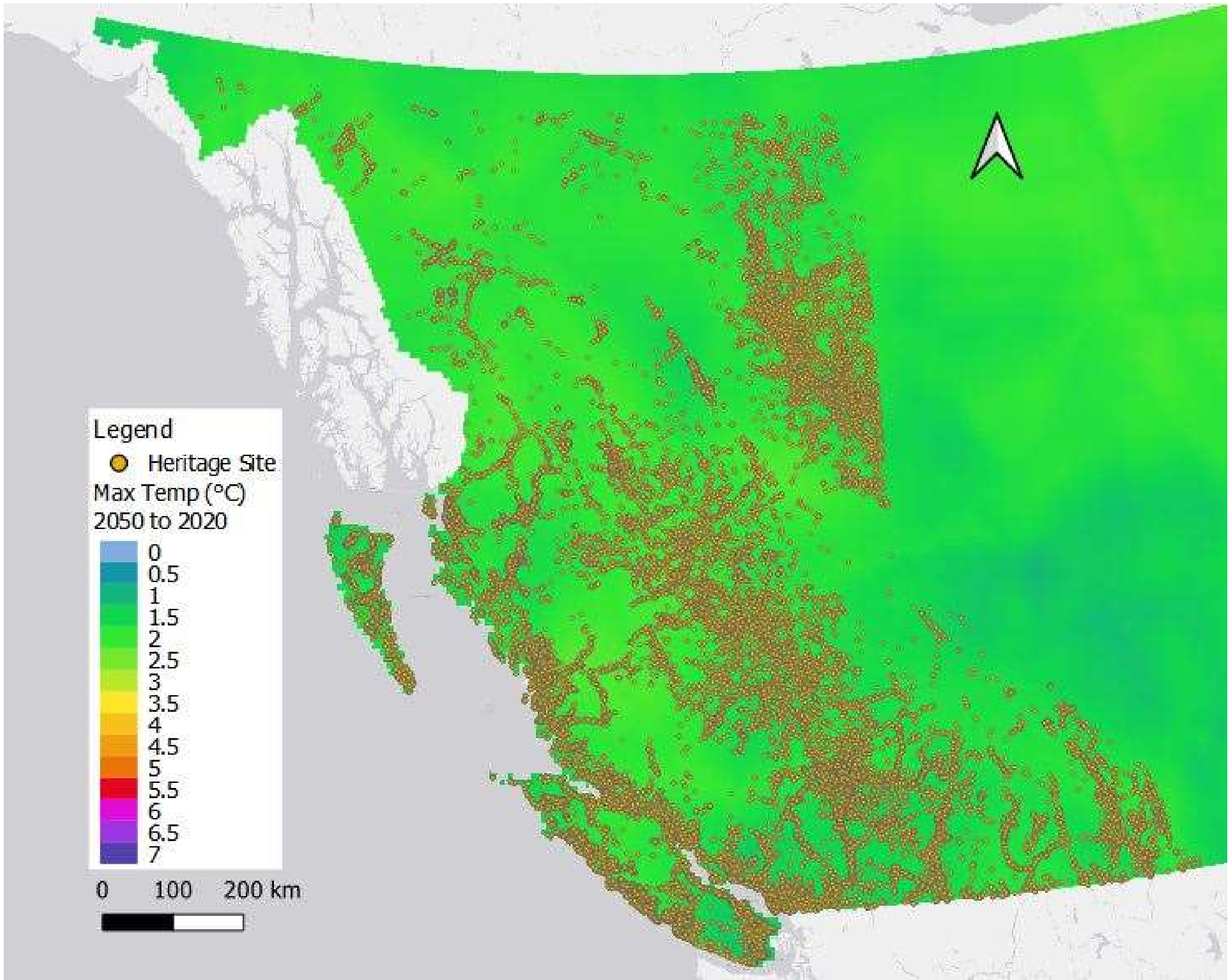

Figure 7. Maximum temperature (°C) 2020 to 2050.

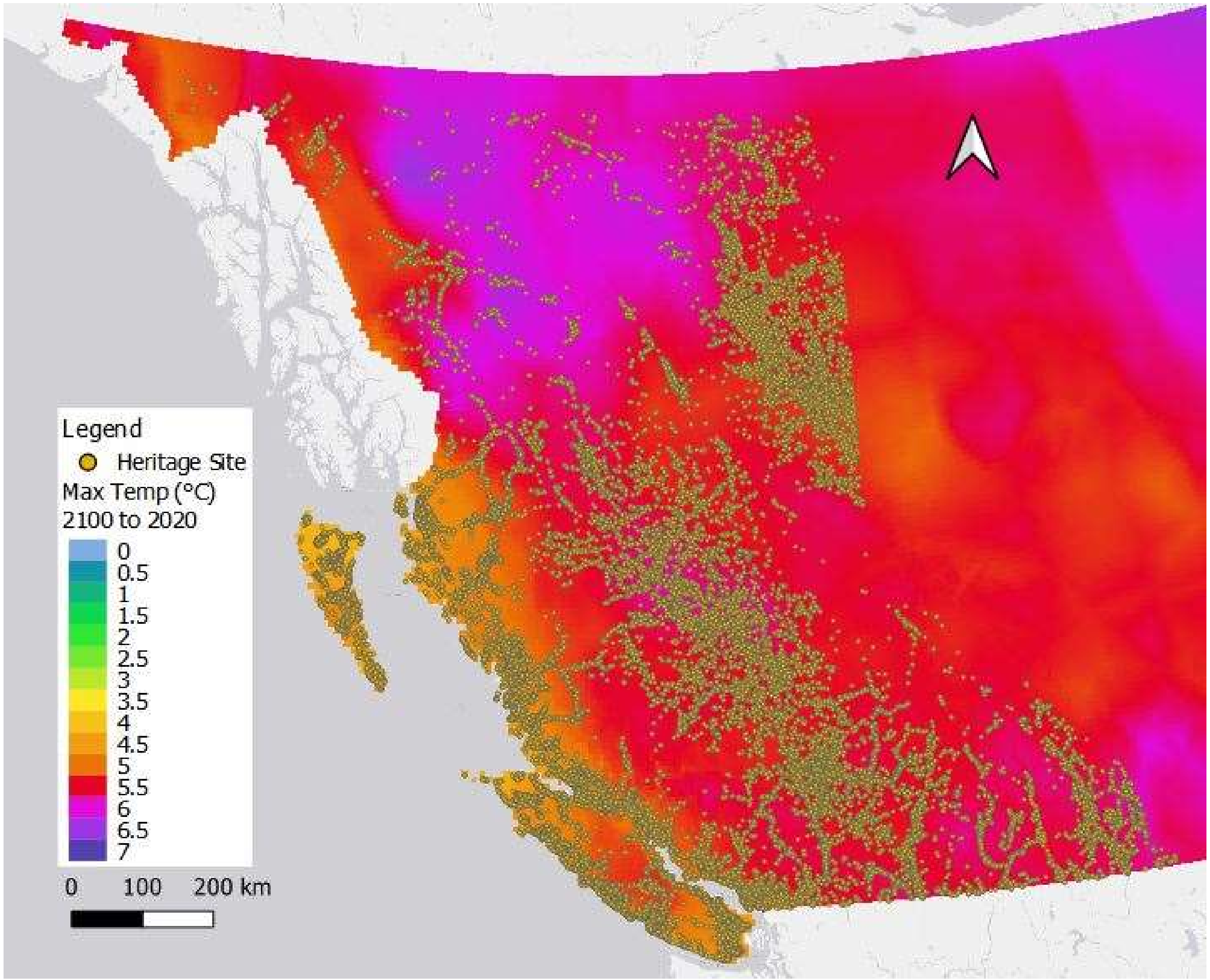

Figure 8. Maximum temperature (°C) 2020 to 2100.

For the maximum temperature scenario between 2020 and 2050, 49,440 sites were in areas that increased in temperature by 2°C and 6,600 sites in areas where the temperature increased by 3°C. For 2020 to 2100, 17,892 sites were in areas modelled to increase in temperature by 5°C, 37,860 sites by 6°C, and 288 sites by 7°C. Overall, there was an increase in maximum temperature model scenario for 2050 from 2 to 3°C and 5 to 7°C for 2100. Both the minimum and maximum temperature calculations show an increase in the number of sites located in areas where 2050 and 2100 model scenarios indicated a rise in temperature.

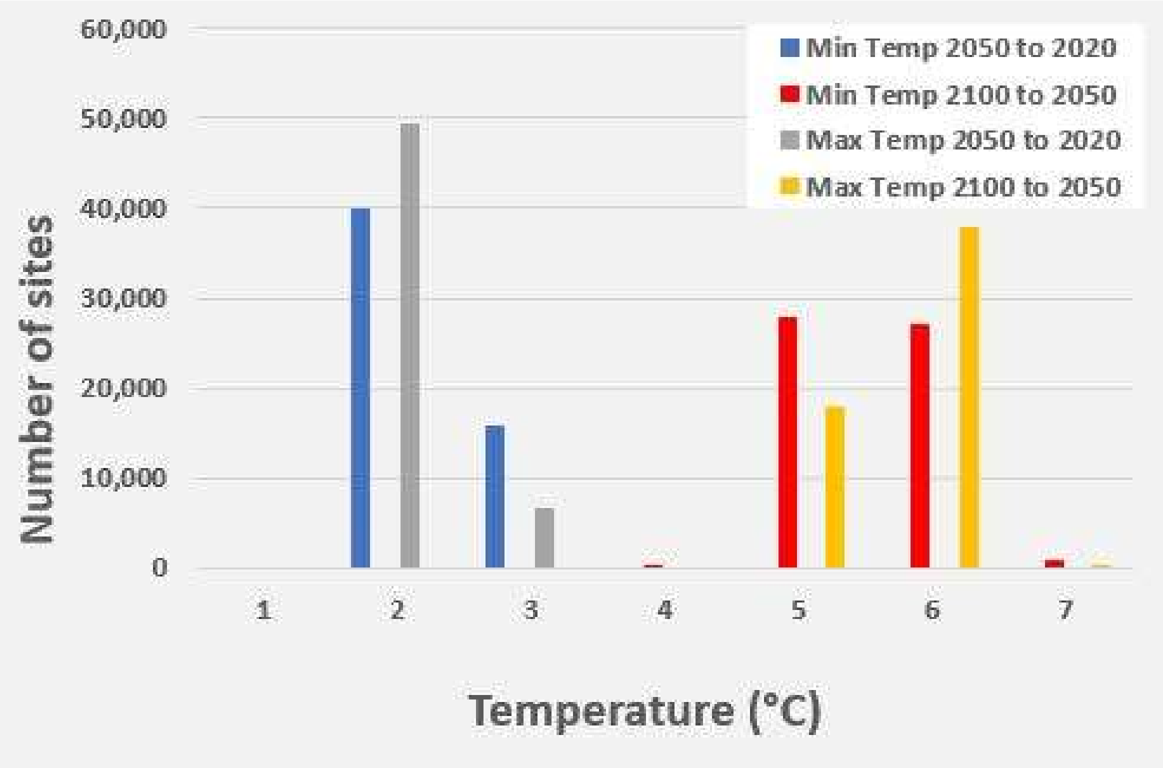

Figure 9. **Number of heritage sites and difference in maximum and minimum temperature.**

4.2.2. Precipitation

A total of 56,040 heritage sites were intersected with precipitation data polygons. The annual modelling scenario indicated the total amount of precipitation predicted over an entire year (Figure 10). The winter modelling scenario indicated the amount of precipitation from December to February and the summer modelling scenario from June to August. Figure 11 indicates the number of sites that intersected with the precipitation model polygon within the time ranges indicated above. The overall annual precipitation rates at each intersected site decreased slightly from 2020 to 2100 (Figures 12–13). From the summer of 2020 to the summer of 2050, the amount of precipitation at each intersected site was predicted to generally decrease. The quantity of precipitation at each intersecting location in the summer of 2100 increased compared to the summer of 2020. For the 2050 and 2100 winter scenarios, the precipitation at each intersected site was predicted to increase.

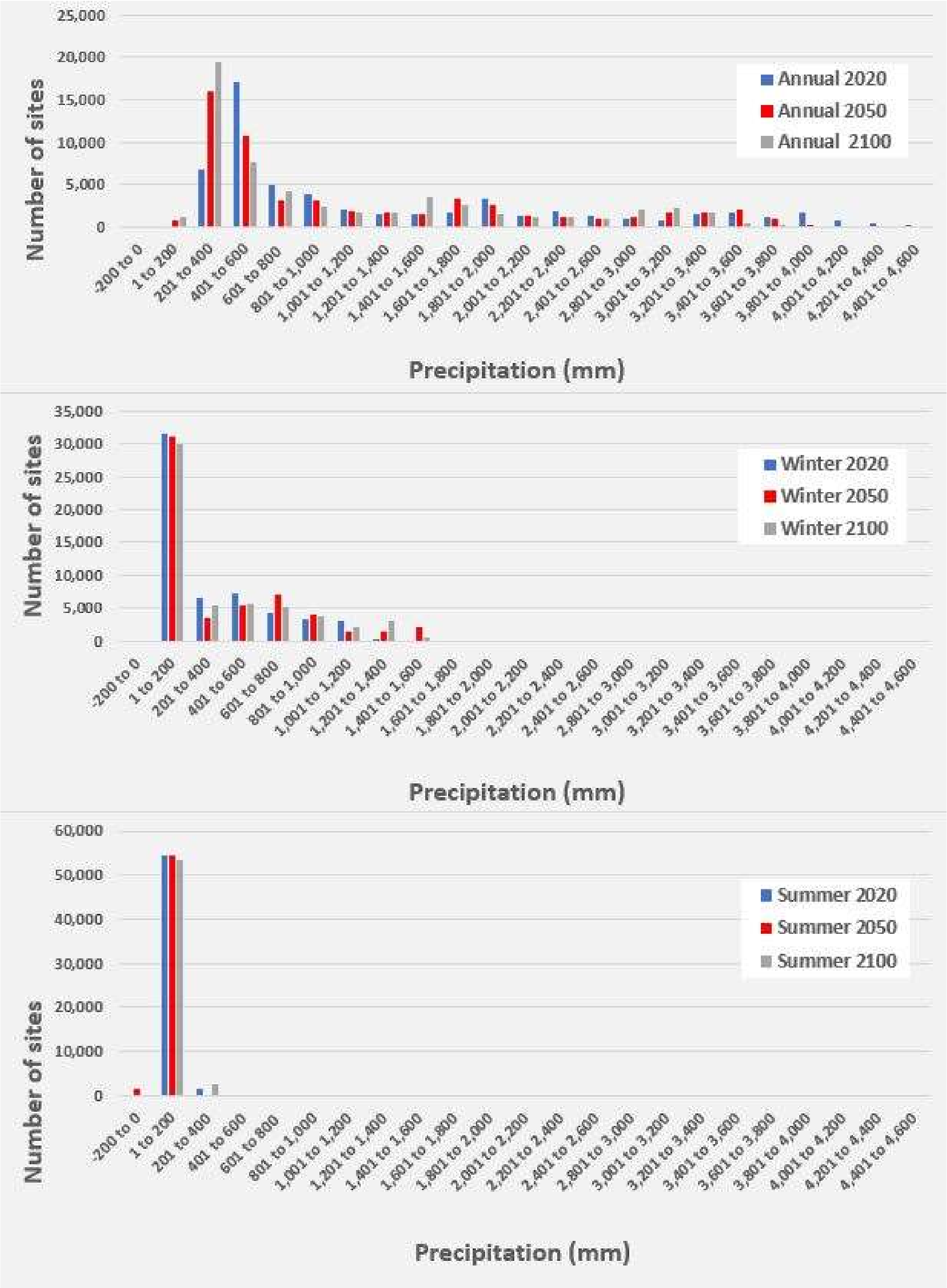

Figure 10. Number of heritage sites per annual, winter, and summer climate change scenarios (2020, 2050, 2100) in 200 mm precipitation increments.

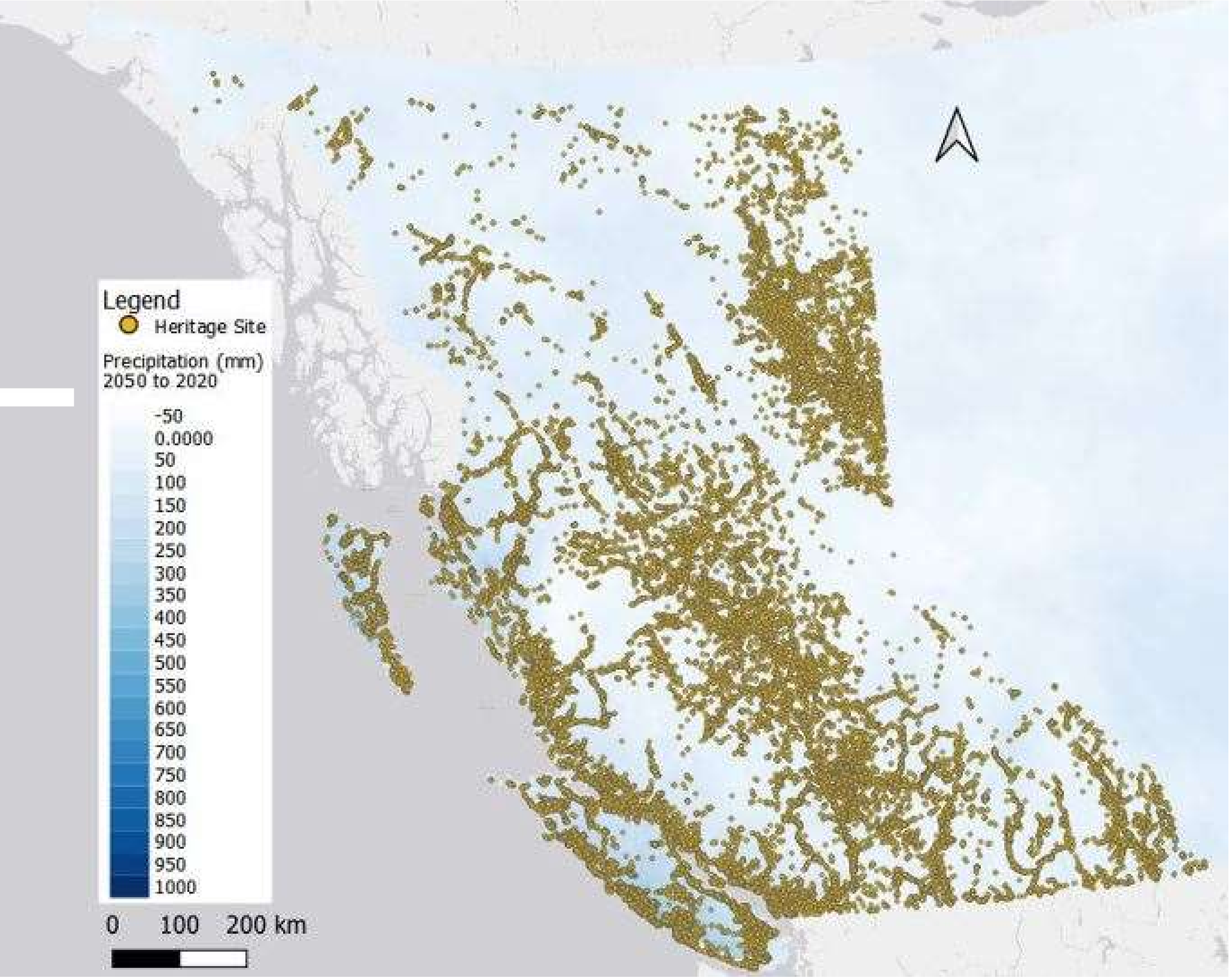

Figure 11. **Total precipitation (mm) 2020 to 2050.**

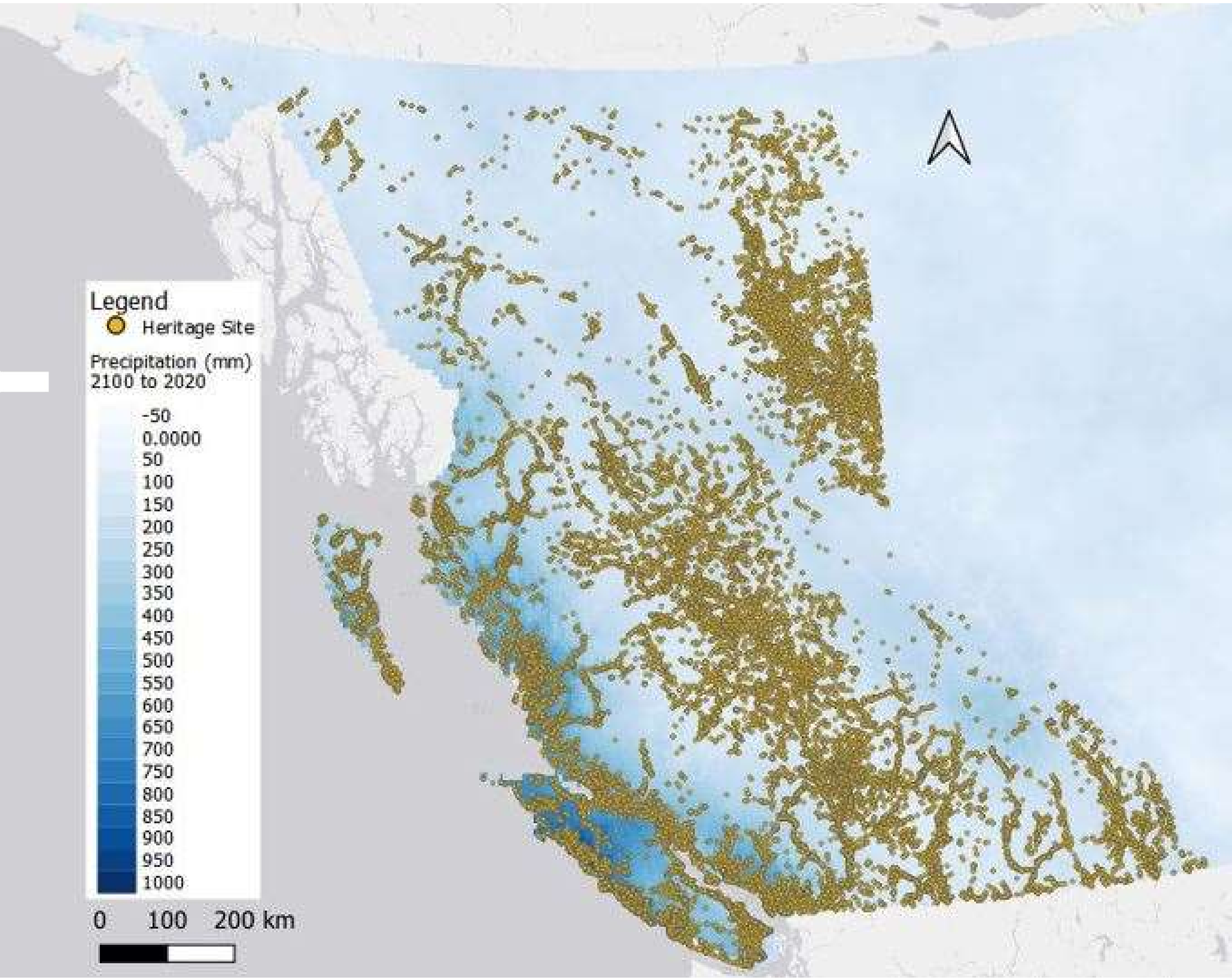

Figure 12. **Total precipitation (mm) 2020 to 2100.**

Figure 13 presents the results of winter, summer, and annual global warming scenarios for the difference in precipitation (both snow and rain) predicted at recorded sites for the time periods 2020 to 2050 and 2020 to 2100. Overall, the annual modelling scenario predicted the amount of precipitation from 2050 and 2100 increased at most sites in the province. Modelled data for the summer of 2050 to 2100 showed precipitation at sites decreased and, in the winter, increased. In the summer months from 2050 to 2100 there was an increase in the number of sites where precipitation decreased below zero millimetres. In contrast, the annual difference in precipitation from 2050 to 2100 indicated a significant rise. Changes in both temperature and precipitation patterns have negative impacts on heritage sites. In the past, changes in temperature and precipitation patterns in British Columbia led to an intensification of indirect climate impacts. For example, sites in forested environments have been impacted by more frequent wildfire events due to drier conditions and a growth in pest numbers due to conditions that support longer periods for them to thrive.

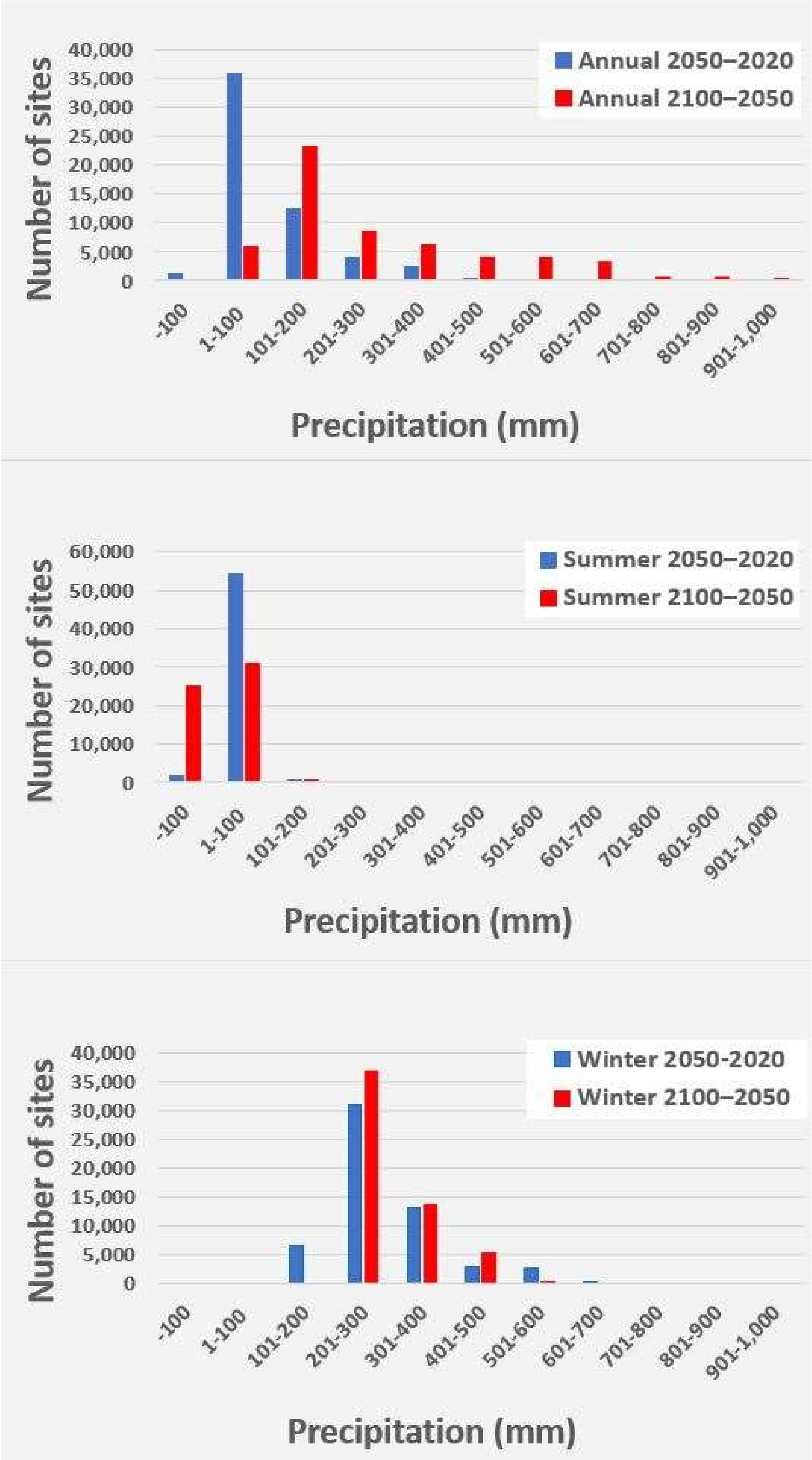

Figure 13. **Number of heritage sites and the difference in total precipitation in 100 mm increments (annual, winter, and summer).**

4.3. Past Climate Change and Heritage Site Dataset Comparison

Areas impacted by wildfires events from 2017 and 2018 and infestation from the 1990s and early 2000s were well documented, with publicly available geospatial data. To predict whether registered heritage sites were impacted by these specific events, the historic wildfires and MPB datasets were intersected with site locations. Of the 58,113 heritage points recorded, 12,105 records were CMT sites. CMT site data were highlighted because these features are highly vulnerable to impacts from pest infestation and wildfires. Here I discuss the number of heritage sites that overlapped with past climate change risk events for wildfire and MPB infestation. I conducted this analysis to determine if the approximate number of hertiage places damaged by past risk events could be calculated using existing datasets. The results of the analysis were compared with information recorded in the provincial heritage registry to indicate past and present site impacts and conditions.

4.3.1. Heritage sites Overlapping Wildfires Areas

Of the 58,113 heritage points in the dataset analyzed, 9,401 intersected with the historical wildfires spatial data from 1910 to 2020 (Figure 14Figure 15). CMT sites accounted for 660 of these intersections. Occasionally, locations of heritage sites overlapped more than one historical wildfire data polygon. Overlap occurred if there were fires in the same area in more than one year. With the increased size of the burned areas, the overlap between historic wildfire polygons and sites has risen dramatically since 2010. It appeared that, after 2010, the number and size of areas burned by natural wildfires were greater than all previous years combined.

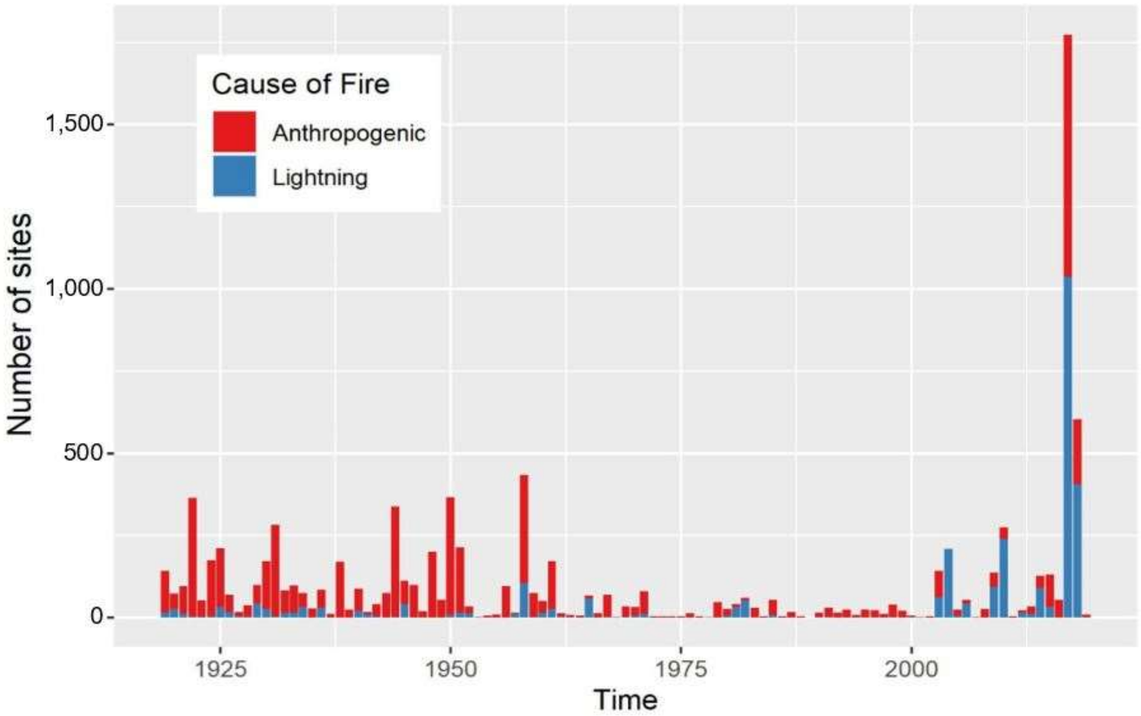

Figure 14. Intersection of all heritage site types and historic wildfires area polygons.

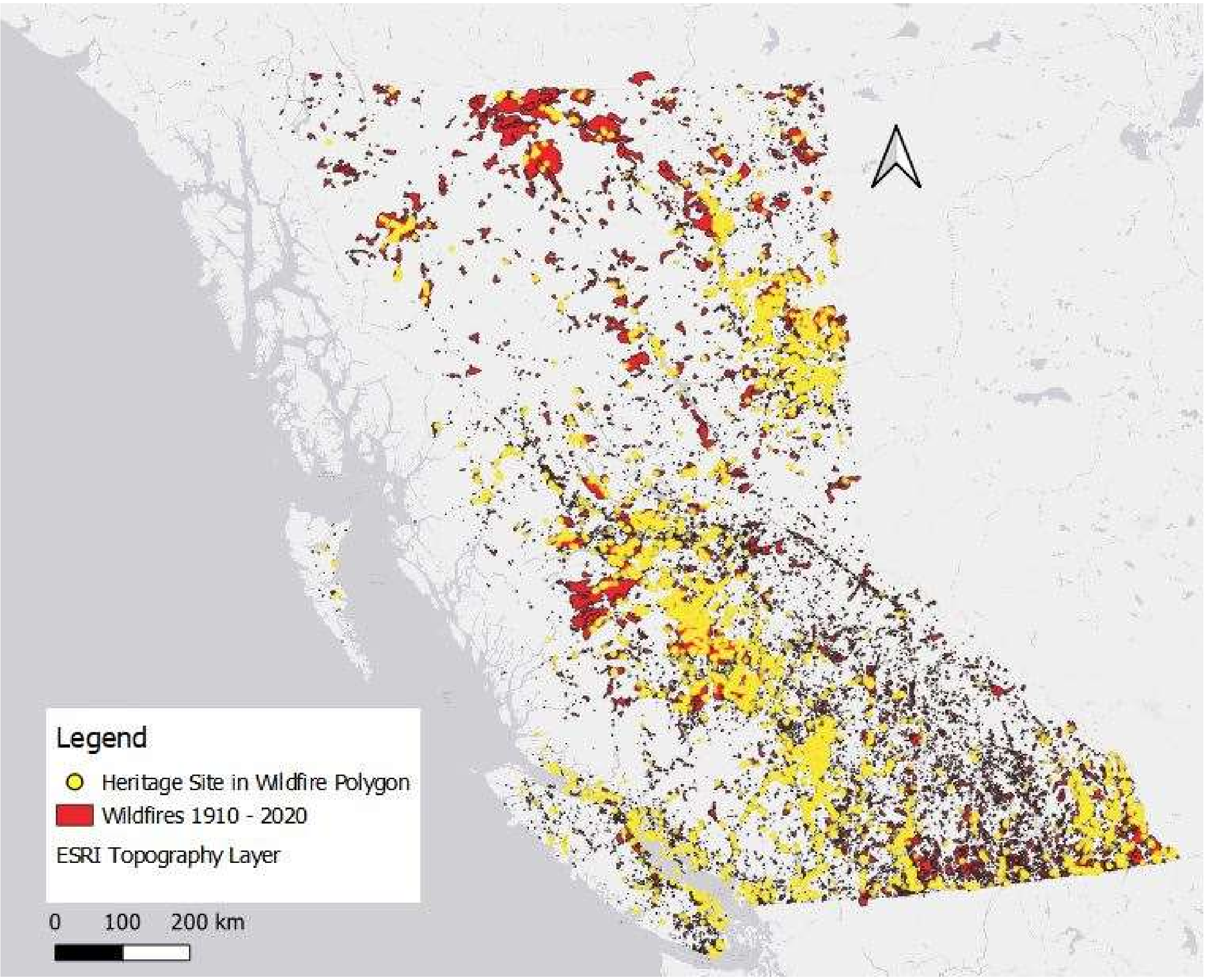

Figure 15. Intersection of heritage sites and 1910-2020 historic wildfire areas.

4.3.2. Heritage sites Overlapping MPB Infestation Areas

Among the 58,113 sites compared, 27,784 overlap with the MPB infestation area polygons. 5,580 CMT sites could have potentially been affected by the MPB epidemic (Figure 16Figure 17). Note the numbers of sites potentially affected by MPB reflect the total intersections between sites and MPB infestation polygons, and some polygons may overlap if infestations were recorded in the same area in different years.

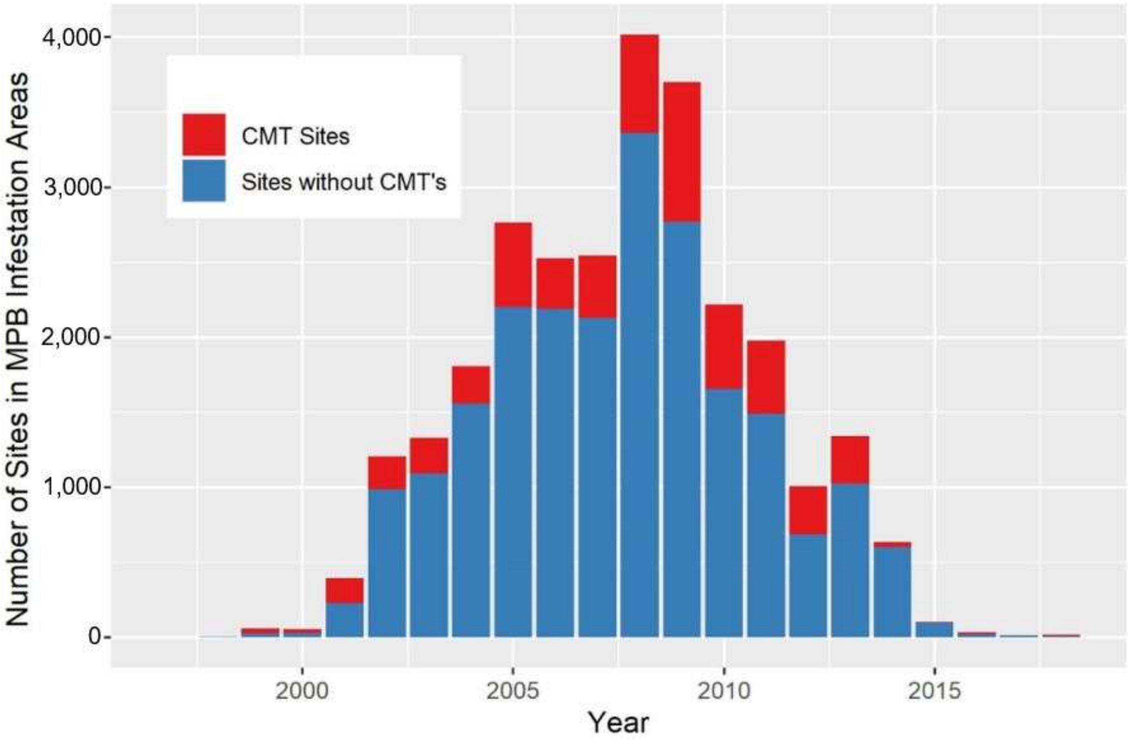

Figure 16. **Intersection of sites without CMTs, CMT sites, and historic MPB infestation area polygons.**

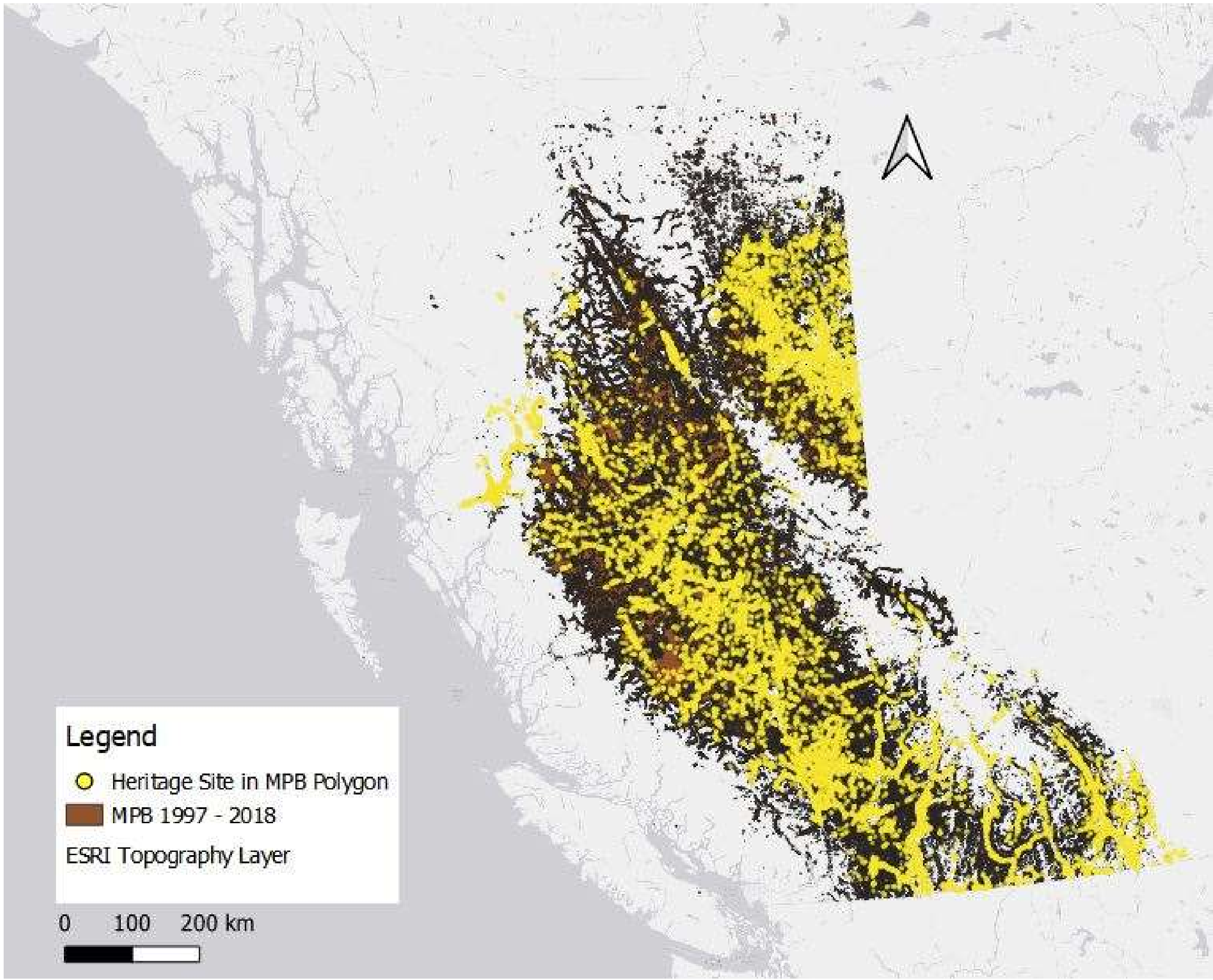

Figure 17. Intersection of heritage sites and 1997 to 2018 MPB infestation areas.

4.4. Chapter Summary

The results of my analysis indicates that a total of 4,722 sites in the province overlapped the coastal sensitivity model. Of these, 9% are predicted to decrease in coastal sensitivity, 67% will have a moderate increase, and 24% will significantly increase. Minimum temperatures are predicted to increase from -7 to 9°C in 2020 to -1 to 13°C in 2100. In comparison, maximum temperatures are predicted to increase from 3 to 17°C in 2020 to 8 to 22°C in 2100. In the 2020 minimum temperature scenario, 40% of heritage sites were in areas with temperatures below 0°C, and in 2100 only 0.2% were in areas below zero. For 2020, 2050, and 2100 maximum temperature scenarios, no sites were in areas with temperatures below 0°C. Most sites in the province are predicted to experience increased precipitation between 2050 and 2100. According to model data for 2050 to 2100, summer precipitation decreased while winter precipitation increased. In the past climate change has potentially impacted 9,401 sites due to wildfire between 1910 and 2020 and 27,784 from MPB infestation.

Chapter 5.

Discussion

This thesis examined four key questions: 1) how many heritage sites are predicted to be impacted by climate change; 2) how climate change would affect sites; 3) what the benefit is of using GIS to identify potentially vulnerable sites; and 4) what can be done to forecast and manage the impacts of climate change on these sites. In this chapter I discuss each in turn.

5.1. How many heritage sites have been predicted to be affected by climate change in British Columbia?

My study results indicate that tens of thousands of British Columbia's archaeological sites and historical places are in areas predicted to have substantial variations in precipitation, temperature, coastal sensitivity, and secondary risk effects such as wildfire and MPB infestation. The coastal sensitivity model indicated that coastal areas at risk contained 4,722 sites. In 2000 1,759 sites were predicted to have very low to low coastal sensitivity and 1,243 sites moderate to very high ratings. By 2090, the number of sites with very low to low coastal sensitivity increased to 2,964 sites and for moderate to very high to 3,480 sites. Figure 18 shows the rise in the number of registered sites in areas with an increase in coastal sensitivity. This suggests there is a greater potential for sites along the coast to be severely damaged or destroyed by future climate change.

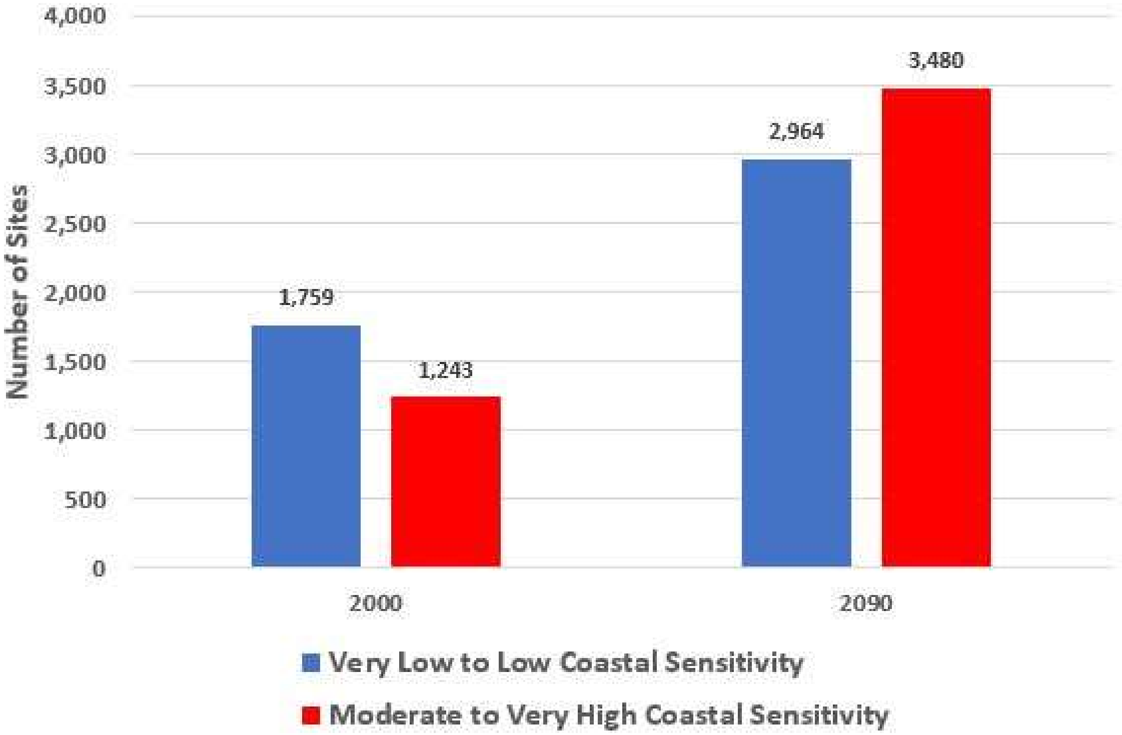

Figure 18. **Number of sites predicted to have very low to low and moderate to very high coastal sensitivity from 2000 to 2090.**

Based on the minimum temperature scenario, temperatures are expected to rise at 53,814 heritage site locations in 2020, 55,937 by 2050, and 56,040 by 2100. The minimum temperature range for all sites increase from 1 to 3°C in 2000 to 4 to 7°C in 2100 (Figure *19*). For 56,040 sites, the predicted maximum temperature increased for all sites for 2020, 2050, and 2100. The maximum temperature range for all sites increase from 1 to 3°C in 2000 to 4 to 7°C in 2100 (Figure 19). More sites are in areas predicted to become hotter in 2050 and 2100 based on both minimum and maximum temperatures calculations. This increase in the number of sites at risk in these areas is likely because the areas where temperatures are predicted to become warmer grew, and correspondingly, the larger area included more sites than for 2020 (Figures 8-9).

From 2020 to 2050, 56,033 sites showed an annual change in expected precipitation. Predicted precipitation patterns continued to change at 56,040 sites from 2050 to 2100. In the summer of 2020 and 2100 the precipitation at all sites was expected to be within the range of -100 to 200 mm (Figure 19). In the winter of 2020 6,502 sites were predicted to be in areas with -100 to 200 mm of precipitation and 49,531 sites will be in areas with greater than 1,000 mm of precipitation. In 2100 all sites in the winter will be in areas with greater than 300 mm of precipitation. Overall, by the end of the 21st century, precipitation at sites will increase in the summer and more drastically in the winter months. There is a likelihood that areas with a warmer climate could have less precipitation, while increased evaporation on the land may worsen droughts and contribute to wildfire conditions.

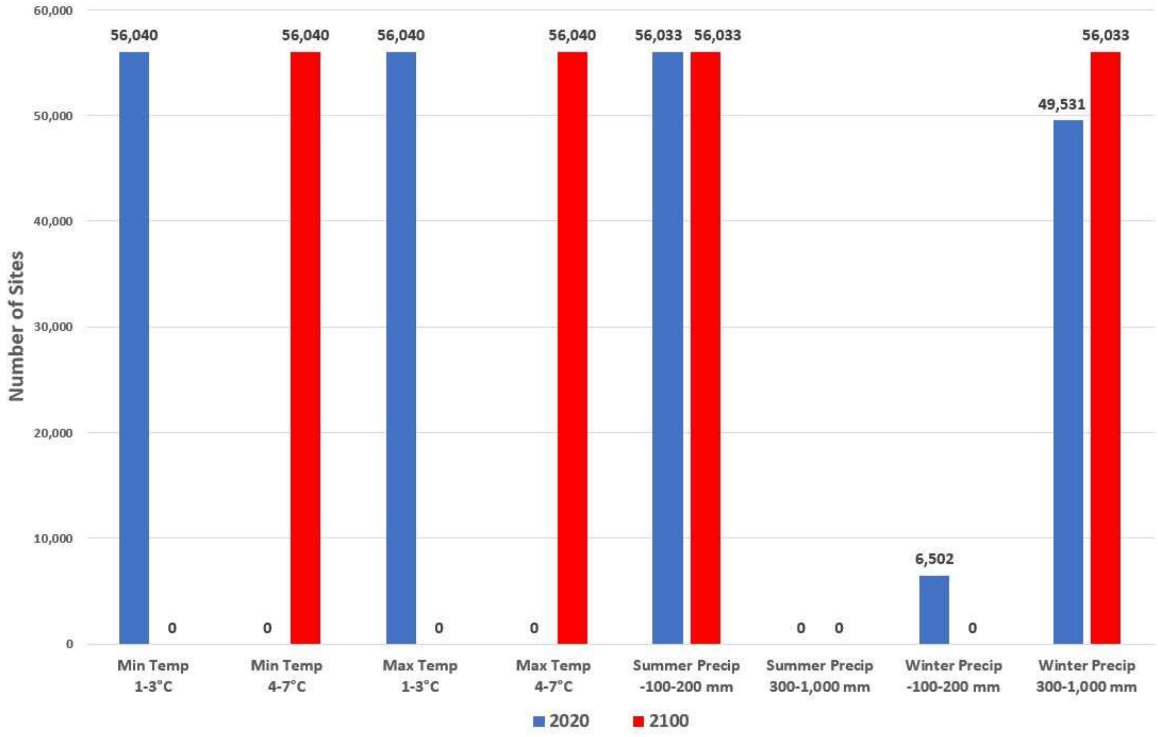

Figure 19. **Number of sites modelled to be impacted by temperature and precipitation.**

Since there was no information readily available on the number of sites affected by climate change during the past century, polygons from past changes only suggested what types of sites *could* be at risk in the future. Events associated with global warming reviewed included wildfires and MPB infestation. The model intersection results indicated that 941 sites overlapped with wildfire polygons recorded between 1910 and 2020. Between 1997 and 2018, 27,784 heritage sites were in areas infested by the MPB (Figure 20). Figure 20 shows the total number of sites that overlapped with areas of past wildfire and mountain pine beetle infestation. Some heritage site types, such as CMTs, are more susceptible to wildfire or MPB infestation than others. Approximately 11% or 6,240 sites that overlapped with wildfire or MPB infestation areas were CMTs. A review of provincial site forms confirmed that climate change events in the past damaged some of these CMT sites, but not all.

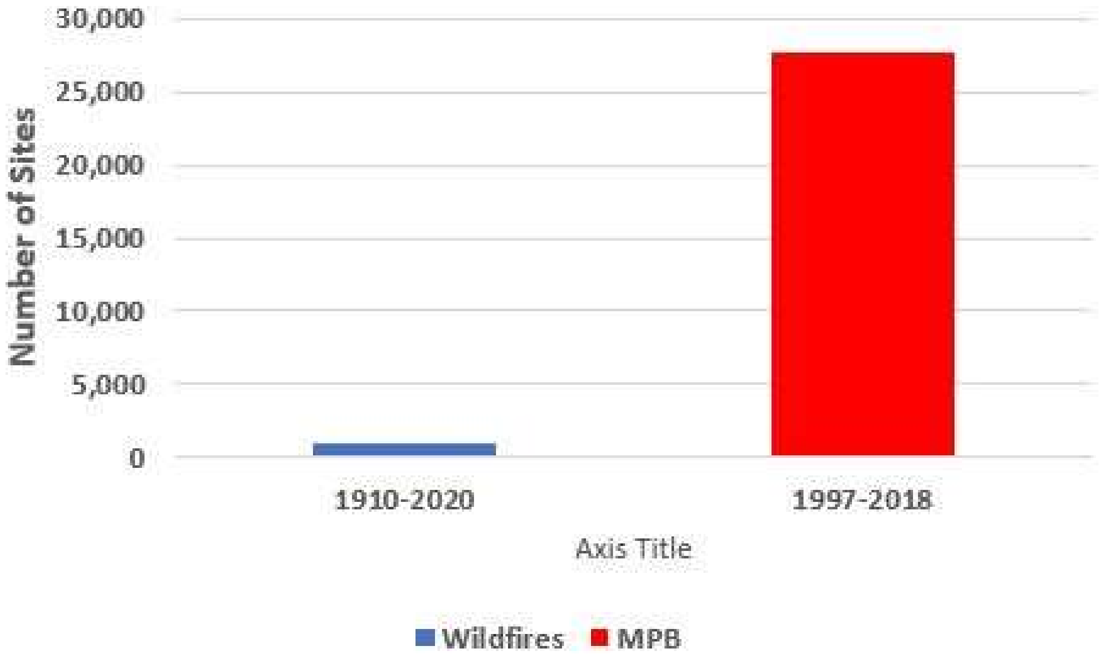

Figure 20. **Total number of sites overlapping past wildfire and Mountain Pine Beetle infested areas.**

Determining the number of sites affected by climate change in British Columbia is not currently possible due to limitations of the climate models and heritage inventory. Six key actions are needed to get a more accurate estimate, relative to:

- Ensuring heritage inventories are complete, searchable, and have consistent naming conventions;
- Completing additional studies to verify the number of sites at risk from climate change impacts;
- Developing localized models incorporating how heritage sites and materials respond to environmental modifications such as temperature, precipitation, ocean acidity, groundwater fluctuation, and shifts in biogeoclimatic regions (Carroll and Aarrevaara 2018:1; Sesana et al. 2021:20);
- Developing localized and regional models specific to predicting impacts to heritage sites from climate events (e.g., flooding, wind, wave, severe weather);
- Conducting research that identifies how climate change impacts sites; and

- Using research on heritage impacts to design a list of vulnerabilities that accurately measure threats that can be applied to regional models to produce a threat map and list of sites used for planning purposes (Forino et al. 2016; Daly 2014).

Although research to predict the number of sites affected by global warming is possible, accurate predictions are very challenging. Although not as accurate as possible, the results of this study can help formulate initial strategies for adapting to climate change. Over time, refinements can be made to the proposed strategies as more research becomes available. The data produced by my study do provide an approximate number of sites, a baseline of the spatial and temporal distribution of sites, and a rating of the severity of impacts from modelled climate changes.

5.2. What changes in the climate can affect heritage sites?

As a result of changes in climatic conditions (e.g., extreme weather events, wildfires, coastal storm surges, flooding, landslides), sites can be physically or chemically altered, resulting in their degradation or destruction (Sesana et al. 2018:1). Impacts from erosion and inundation due to sea-level rise, severe storms and storm surges may also adversely affect coastal sites (Fenger-Neilsen et al. 2020:1281). My study indicates 4,722 coastal sites are in areas predicted by the CanCoast model to be damaged or destroyed. In addition to the modelled effects, urban areas of the coast may be impacted where there are planned mitigation efforts such as construction of coastal defences. It is important to note that not all climate changes will adversely affect heritage sites; some types of sites may not be affected at all. There could, however, be a variation in the extent of the impact between sites. Site types such as lithic scatters may only be affected by extreme risk events like wildfires, flooding, or landslides. Coastal uplift should reduce the impact of sea-level rise on some coastal sites. Alternatively, sites on glaciers may only be affected if temperatures rise, causing glaciers to melt and expose them.

An increase in temperature may not affect all site types but could have significant impact on the preservation of organic materials as observed in Greenland where up to 40% of organics materials decayed when temperatures increased from 2.2 to 5.2°C (Hollesen et al. 2017:1186). Minimum and maximum predicted temperature rise in British Columbia were in a similar range as Greenland's but the impact on sites resulting from temperature rise is unknown due to a lack of previous studies. Various assessments conducted in the province have identified effects on heritage sites from climate change. Wyatt's 2015 study in the Gulf Islands indicated sea-level rise, king tides, more severe storms, sea surges, coastal floods, wave overtopping, rain runoff, and wind and wave action threaten sites located along British Columbia's coastline. The study conducted by the Tahltan Central Government at Mount Edziza in 2019 identified impacts on perishable artifacts exposed by melting ice patches. Additionally, numerous assessments were conducted following wildfires, beetle infestations, flooding, and severe storms that have affected different types of heritage sites throughout the province (Cohen 2019:1-4; Dyok 2020; Klassen et al. 2009:215; BCMoE n.d.; Tahltan Central Government 2020:22). Information on these assessments is available in the Provincial Heritage Register.

Site registration form records in the provincial database include information on the past, present, and future condition of each heritage site. Site records indicate that 44 registered heritage sites were impacted by wildfires between 1910 and 2020 (seven are included in the site and wildfires data intersection[25]). Given that 9,401 sites potentially could have been impacted by wildfires, the low number of wildfire-altered sites is surprising. There are several reasons why wildfire impacts may not appear in the Provincial Heritage Register, including: site form updates were not processed; heritage sites were recorded before the impacts of wildfires; very few post-impact assessments have taken place; wildfires did not impact sites; or site condition information was incomplete.

Within the "conditions" section of the site registration form, 455 forms indicated impacts from MPB infestation were observed in the past or present or would likely be impacted in the future. In the historic site and MPB infestation data intersection, 220 CMT sites were included. The number of CMT site forms noting pest infestation was low, considering there was a total of 5,580 CMT sites that could have been impacted by MPB infestation. The reasons for the lack of MPB infestation impacts recorded in the Provincial Heritage Register are the same as why wildfires may not have been recorded (i.e., site form processing, recording prior to infestation, and low number of post-impact

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[25] The remaining 37 sites either had invalid geometry and could not be plotted or they did not overlap with the historical wildfire polygons.

assessments, as well as the possibility that very few sites were impacted by MPB). Although the provincial registry includes limited information on climate change impacts on sites, improvements are needed to routinely record observed effects consistently and with increased detail. Including more detailed information on observed impacts in the registry could assist in identifying vulnerable sites and mitigating impacts prior to losing valuable data on heritage sites. Training heritage field personnel to identify and mitigate climate change impacts in the field is one way to achieve this.

Based on my analysis, I could not fully determine what impact climate change will have on heritage sites. The output datasets from my study contain information that could be used to predict the climate at specific locations. For example, the datasets contain information on the type of heritage site (e.g., wet site, lithic, CMT) and the severity of impacts (e.g., prediction for precipitation, temperature, coastal sensitivity). The ability to look up how the climate is predicted to change at specific sites versus relying on generalized overviews of global impacts means that heritage managers in the province have access to baseline data needed to help determine site impacts. To improve the value of this analysis further, individual sites would have to undergo a qualitative vulnerability risk analysis that examines various factors such as probability, rarity, possibility, and certainty of impacts from climate change. This style of vulnerability risk analysis is like what is prepared for by the AleRT program in France and the CITiZAN program in England to assess risk (Carmichael 2018:4). Although the detailed output datasets needed to complete this analysis are not presented in my thesis, this information is available upon request. I also recommend that the Provincial regulator create similar risk and vulnerability maps and make them available to heritage managers.

5.3. What benefit is there in using GIS software to overlay known sites, predictive climate change models, and past climate change event polygons to identify threats and vulnerable heritage sites?

Computer-based global warming simulations have been used to make accurate climate change predictions on a global scale since the 1970s (Hausfather et al. 2020:5-8). These models are developed to provide valuable information about the current state of the world’s environment and predict how it could change in the future. A wide range of global and regional climate event scenarios can be predicted based on model data, including changes in temperature and precipitation patterns and sea-level rise. To address climate change, heritage managers need to identify where impacts could take place and what sites may be affected. In regions like British Columbia already experiencing climate change's effects, heritage managers must act now to preserve threatened heritage sites.

Coastal sensitivity modelling can determine which locations are most vulnerable to rising sea levels. Precipitation and temperature models can help determine which sites require attention based on anticipated impacts. By modelling these impacts, managers can prioritize work and respond more proactively. Wyatt's study of the effects of sea-level rise on clam garden sites recommended that future work on coastal sites consider sea-level rise (Wyatt 2015:11). For example, wet sites need stable, cool temperatures and moist conditions for optimal preservation. If precipitation decreases and temperatures increase, heritage managers should consider whether mitigation work can take place.

Wyatt also recommended modelling to help determine the age and location of previously unrecorded features (Wyatt 2015:54). Given that a large portion of British Columbia lacks a heritage inventory survey, utilizing potential archaeological models in conjunction with climate change prediction modelling could help identify sites before global warming affects them. Heilen et al. (2018:264-266) used models to identify areas with potential for locating unrecorded heritage sites as a large portion of their study area along the coast of Germany and the southeastern United States had not been thoroughly surveyed or assessed to modern standards. Integrating climate change models, known site locations, and predicted site locations allowed Heilen et al. (2018) to address the lack of survey in their study. Similar work should be conducted in British Columbia to identify areas of potential for unrecorded sites susceptible to impacts from the effects of global warming. If it is not, then areas with a high likelihood of locating heritage remains could disappear and be damaged prior to being investigated (Cassar 2005:26).

GIS-based models are powerful tools for visualizing and analyzing heritage site and landscape changes. The software can analyze vast amounts of data over a large area, producing information needed to assess global warming impacts on provincial heritage sites and assisting heritage managers in designing future mitigation and recommendations. Another benefit of modelling impacts is identifying significant issues before sites are affected and using this information to prioritize work and set goals and expectations for site management. With enough lead time, consultation with Indigenous communities, the public, and other concerned stakeholders can take place to establish meaningful management goals. Model mapping and high-level goals relay critical information regarding the consequences of climate change to a broader audience (Wyatt 2015:60-61).

5.4. Can anything be done to improve climate change forecasting and management of the impacts on heritage sites?

Heritage managers in the province could benefit significantly from regional models that predict climate change impacts on heritage. Three topics deserve some discussion here: 1) the intersection of coastal sensitivity; 2) temperature and precipitation, and 3) wildfire and MPB infestation polygons and how this work could be improved to better predict the impacts of climate change on heritage in British Columbia.

5.4.1. Coastal Sensitivity

The CanCoast model indices include sea-level change, decadal mean wavelength, ground ice, surficial geology, slope, and tidal range (Manson et al. 2019:3). By comparing these indices, it was possible to identify coastal areas sensitive to climate change. Figure 21 visualizes the intersection of recorded heritage sites and the CanCoast model. Scores assigned to each coastline section were based on the degree of vulnerability. The numeric scores in the model output do not include detailed information on specific impacts or indices. In addition, the CanCoast model did not include indices for coastal erosion, saltwater intrusion, storm damage, flooding, changes in land use, or existing engineered protection. Including more indices should improve the model accuracy. More detail on what indices were triggered by the model could aid in determining site vulnerability so mitigation or monitoring work for threatened sites can be prioritized (St. Amand et al. 2020:1761).

A disadvantage of the CanCoast model is each data point is presented as a polyline feature following the coastline, with different sections marked with sensitivity scores. Because of this, the model does not identify sensitive near-shore or inland portions of the coastline that would be vulnerable to flooding or groundwater saturation. Consequently, the overlay of data sets may miss sites potentially affected by coastal climate events such as flooding or ground water saturation. The detailed view of the CanCoast model provided in Figure 21 shows that although two sites intersect with the polyline data, several heritage site polygons within 500m do not intersect and could be impacted by sea-level rise, storm surge, flooding, or groundwater saturation. Changing the model’s parameters to capture near-shore sites would increase its effectiveness in identifying vulnerable sites. If the model was updated to include near-shore sites, the number of registered sites predicted to intersect with the coastal sensitivity polygon could be much higher than the 4,722 currently modelled using the polyline feature.

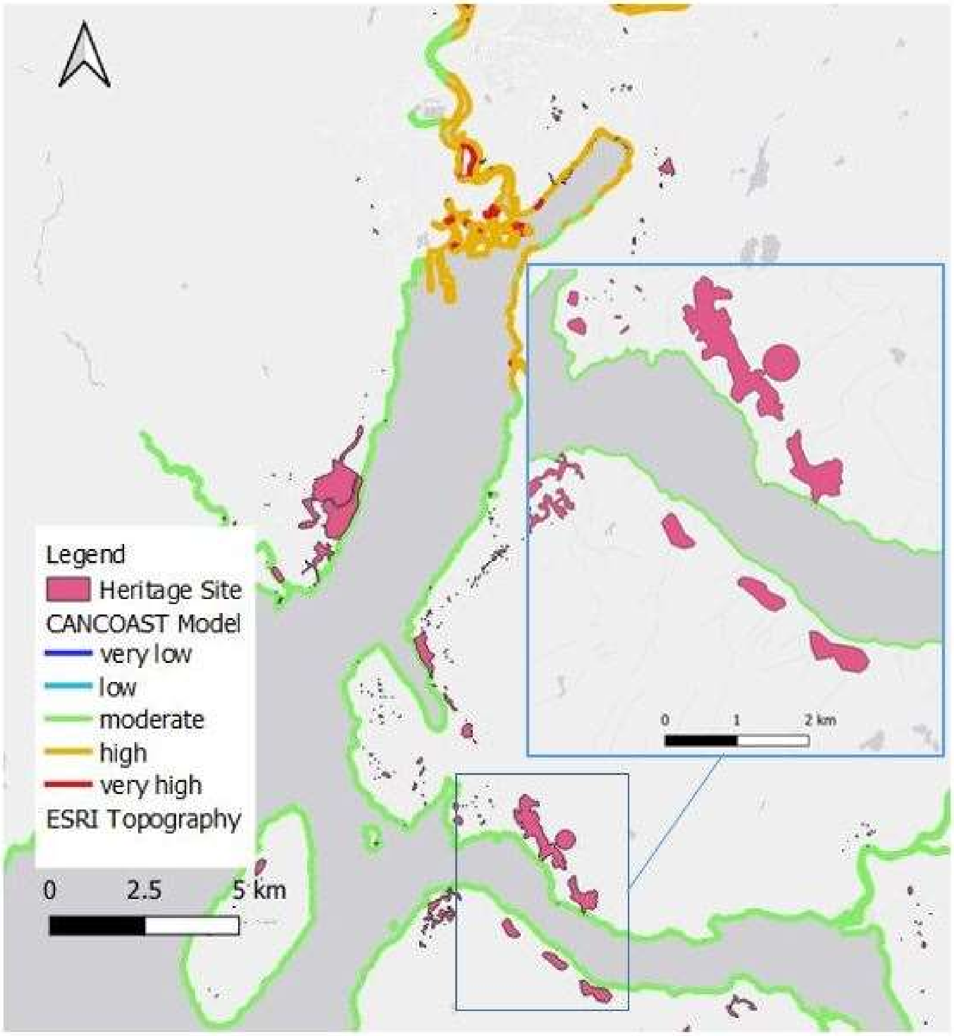

Figure 21. **Detailed view of coastal sensitivity site intersection. Inset illustrates some sites close to the coastline do not overlap the modelled area.**

5.4.2. Temperature and Precipitation

As with the CanCoast model, the CCCS model data used for the temperature and precipitation analysis are at a low resolution, represented as pixels of 6km by 6km squares (Figure 22-25). The high number of sites that intersected with areas predicted to have climate change raises questions about the model's effectiveness in identifying vulnerable sites. Temperature and precipitation data alone are not enough to determine if sites are vulnerable to climate change. More background information is needed to develop a profile of what climate changes, climate change events, and other factors would be needed for heritage managers to make such an assessment. It is evident that each region will have different threats (e.g., changes in: biogeoclimatic zone vegetation species, shoreline erosion, moisture levels, and temperature), based on the severity of climate change, biogeoclimatic zone, and site types found.

Using the intersection data results, sites that could be most vulnerable to temperature increase beyond a certain range can be easily identified. For example, the minimum temperature model results indicate there are 22,401 sites located in areas where average annual temperatures are below zero. By 2100, only 199 sites are in areas with temperatures below zero. A search of the intersection results could be performed to determine which of these 199 sites contain or have potential to contain materials that could be lost as temperatures increase above freezing. Like the research conducted in Greenland (Hollesen et al. 2018:1), studies could take place to investigate how changes in temperature and precipitation ranges impact the various site types and materials found in British Columbia.

Detailed information on temperature and precipitation is needed to support the development of more accurate predictions of how climate change and risk events could impact heritage. One of the most impressive features of the CanCoast model is the flexibility to examine multiple variables (e.g., minimum, and maximum temperature fluctuations and total precipitation amounts annually, monthly, or seasonally). Temperature and precipitation data from the CanCoast model could be input into tools to assess risk for events such as wildfire or extreme precipitation and their impact on heritage (Carroll and Aarrevaara 2018:4-5). Risk analysis tools for coastal sites, like the AleRT program in France or the CITiZAN program in England, could also be developed for the province to help determine if specific heritage sites or types of heritage are sensitive to threats based on the severity of the predicted change, rarity, likelihood, possibility, and certainty (Carmichael 2018:4).

It may be possible, for example, to develop criteria to evaluate threats posed by modelled changes. Each criterion would be weighted, and the risk based on the scale. Datasets like these could also be used to quantitatively analyze individual sites or a particular type of site. From the 2020 datasets, a baseline could be established for the temperatures and precipitation of all sites containing wet site materials. If predicted changes occur, they could be examined to see if conditions changed, how severe the changes were, and whether preservation of heritage sites or belongings was affected. Another scenario could be to examine CMTs to determine their vulnerability to wildfires, pest infestation, or drought. Further study could be prioritized for heritage sites with the highest risk.

5.4.3. Wildfire and MPB Infestation

Comparing site locations to past wildfire and MPB infestation areas provided a rough estimate of the maximum number of registered sites potentially impacted by these climate risk events. This suggests sites that do intersect may be at higher risk than those that do not, but only for the variables they are compared to (e.g., wildfires, temperature, precipitation, MPB). This method was not suitable for accurately identifying the total number of sites vulnerable to climate change from these impacts. Especially considering many sites or site types used in the analysis may not be vulnerable to climate effects. For example, CMTs are vulnerable to MPB, but this threat does not impact all species of trees that are commonly modified (e.g., Western redcedar) because this pest largely attacks and kills lodgepole pine trees. However, the data do highlight a need to develop models that can predict the impacts of severe climate change risk events for the various biogeoclimatic regions in the province (Carroll and Aarrevaara 2018:1-4). Currently, there are no models for this area designed to predict the effects of climate change on heritage sites. Developing models that can predict risk can help to either reduce or prevent impacts from extreme climate change events or disasters (British Columbia Ministry of Forests and Range Wildfire Management Branch 2009:5-8; Carroll and Aarrevaara 2018:4-5; Sabbion1 et al. 2008:17).

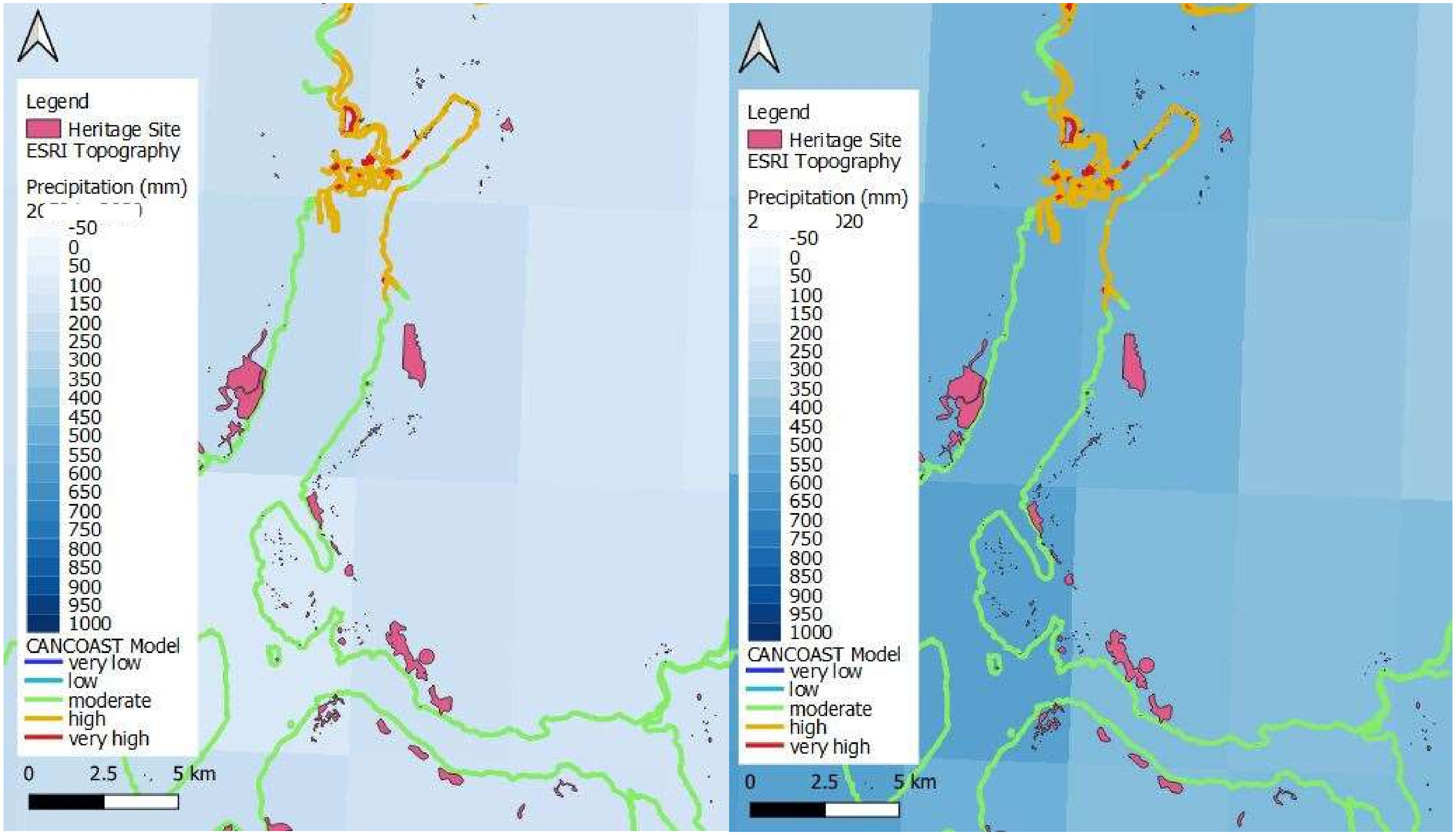

Figure 22. **Detailed view of total precipitation from 2020 to 2050 and 2020 to 2100 illustrating the size of model polygons and differentiation between sites.**

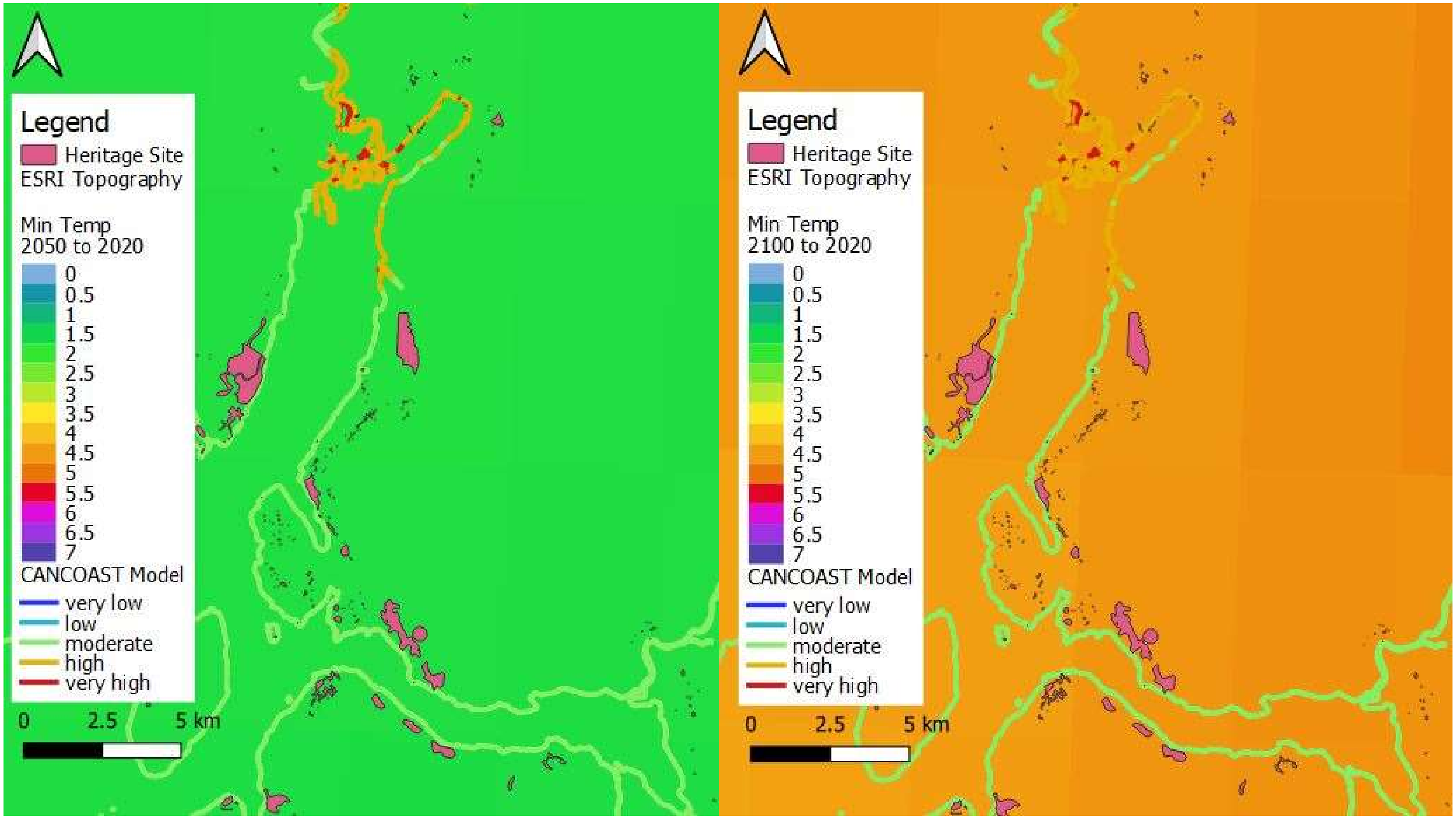

Figure 23. **Detailed view of minimum precipitation from 2020 to 2050 and 2020 to 2100 illustrating the lack of model differentiation between sites.**

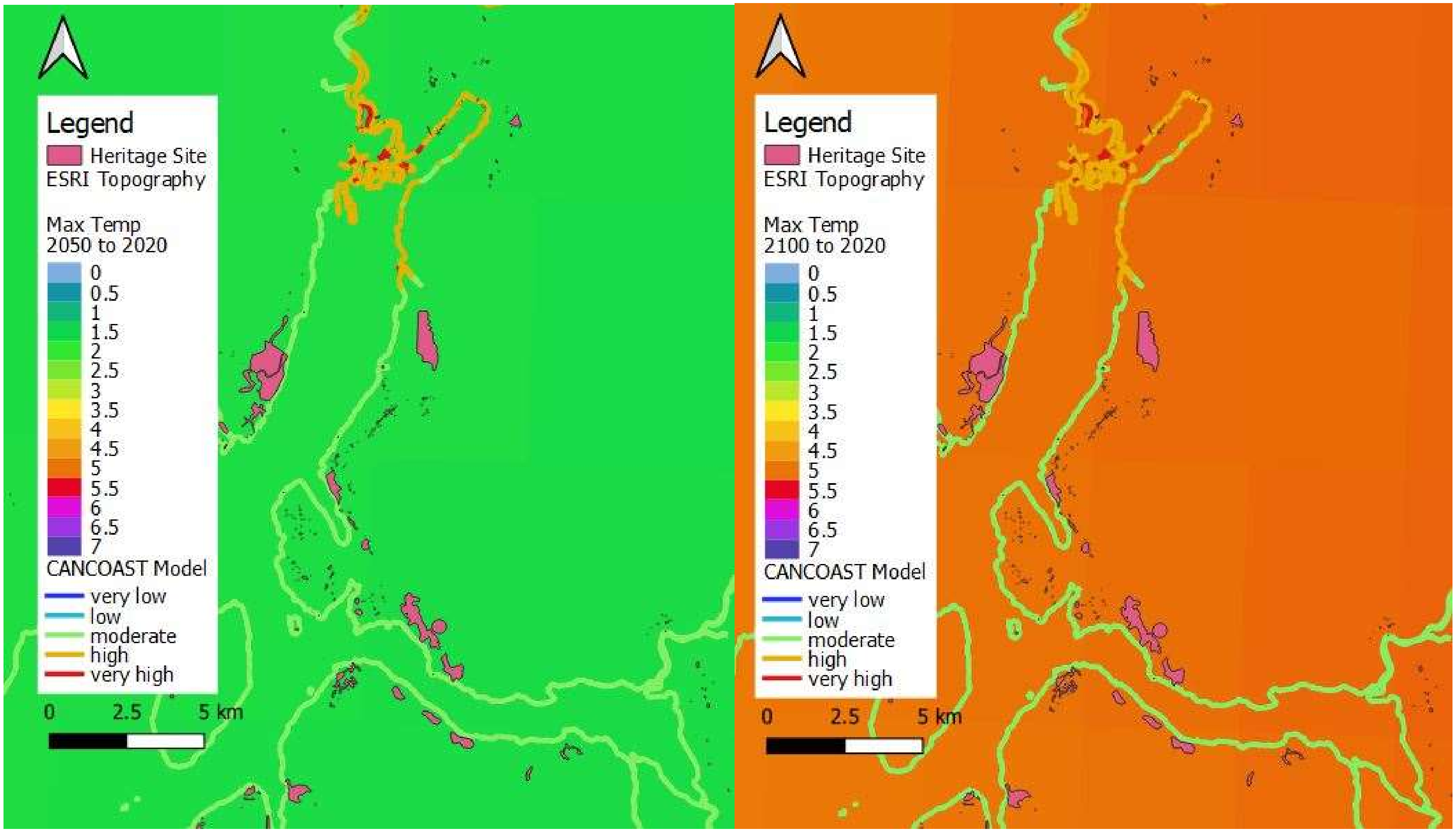

Figure 24. **Detailed view of maximum temperature from 2020 to 2050 and 2020 to 2100 illustrating the lack of model differentiation between sites.**

5.5. Chapter Summary

Based on my study, 4,310 sites were predicted to have a moderate to high increase in coastal sensitivity. Minimum temperature change is forecast between 2020 and 2050 to increase by 2°C for 40,094 sites and 3°C for 15,946 sites. From 2020 to 2100, the modelling indicated 3 sites will increase in temperature by 4°C, 28,009 by 5°C, 27,225 by 6°C, and 803 sites by 7°C. Between 2020 and 2050 the maximum temperature will increase by 2°C for 49,440 sites and by 3°C for 6,600 sites. It is predicted that maximum temperatures will increase by 5°C at 17,892 sites from 2020 to 2100, 6°C at 37,860 sites, and 7°C at 288 sites. From 2020 to 2050, 56,033 sites are predicted to have an annual change in precipitation in 2050 and 56,040 sites in 2100. Extreme storms, flooding, increased erosion rates, increased temperature, and changes in precipitation patterns will be the main effects of climate change on coastal archaeological sites.

In the interior, documented impacts on heritage from wildfires and MPB in the last thirty years highlight how severe the threat has and may be in the future. GIS tools can greatly improve the ability to predict climate change impacts on heritage sites. However, some investment needs to be made to improve the quality of the heritage data available in the Provincial Heritage Registry. This should include incorporating climate change modelling information on heritage management (e.g., layer in GIS based Provincial Heritage online Registry) and then providing guidance as to how it should be used by heritage managers.

Chapter 6.

Conclusions

Heritage managers must understand the extent of the threat climate change poses on historical and archaeological sites to effectively manage impacts. In this study I try to determine whether heritage managers are prepared for global warming impacts on heritage sites in British Columbia by creating preliminary risk mapping.

The results I present here suggest heritage sites are located within areas where climate change models predict changes in coastal sensitivity, minimum and maximum temperature, and total precipitation. The data reviewed also support the fact that an increase in climate change events over the last century, such as wildfires and pest infestation, have damaged or destroyed vulnerable sites. What is not known is the exact number of sites affected in the past or the future. Recent climate change events do confirm sites may be impacted by more than just gradual changes in climate from predicted temperature rise and changes in precipitation patterns. They could also be damaged by sea-level rise and extreme climate events such as wildfire, MPB, floods, and landslides.

Another critical factor in preservation is developing and implementing effective intervention or management solutions. There is a close relationship between heritage properties and the surrounding area, ecosystem, community, and society. They are not isolated areas; their safeguarding depends on the support of communities. It is therefore fundamental to increase awareness of the connectivity of climate change and interactions between decision makers, communities, stakeholders, and natural and cultural heritage to support transformative change (UNESCO 2021:19). In combination with climate change, natural environmental processes impact and accelerate the degradation rates of vulnerable archaeological heritage sites (Carroll and Aarrevaara 2018:1-4). Whether or not heritage sites are preserved largely depends on the site type, setting, natural processes, severity of climate change events, and the interests of stakeholders. Preservation also depends on the people who decide the fate of the sites and materials that are threatened by global warming (Watkins and Beaver 2008:31). The 2015 Sustainable Development Policy expressly recognizes the linkages between climate change and sustainable development, noting that “in the face of increasing disaster risks and the impact of climate change, governments should recognise that world heritage represents both an asset to be protected and a resource to strengthen the ability of communities and their properties to resist, absorb, and recover” (UNESCO 2021:19). In British Columbia governments, local communities, and heritage professionals have not prioritized the protection of heritage from the affects of climate.

The findings show the importance of using modelling to assess climate change impacts on heritage sites at a regional level. This method has assisted in identifying sites vulnerable to climate change. Additional work can be done with this information to prioritize sites and focus resources so that important heritage sites are not lost. However, preservation alone is not enough. It is crucial to allow communities whose heritage is at risk to make decisions regarding its management, especially when there are not enough resources to preserve all the sites (Holtorf and Kristensen 2014:313; Watkins and Beaver 2008:16). Most importantly, community involvement in decision making is imperative because people who have ties to places and connections to materials are impacted by the actions of heritage managers (Watkins and Beaver 2008:31). The adoption of Declaration on the Rights of Indigenous Peoples Act (DRIPA) by the government of British Columbia and the use of shared decision-making process to establish jurisdiction and authority for First Nations to manage their own heritage (Schaepe et al. 2020:61). This may help to address concerns raised by First Nations regarding the ability to protect heritage from climate change effects (British Columbia Heritage Branch 2021:3).

6.1. Recommendations for Heritage Managers

This thesis contributes a new and unique risk analysis of the impact of climate change on heritage sites in British Columbia. Prior to this study, there were no assessments to indicate the number of sites potentially vulnerable to climate change in the province. However, based on the results of this research, and what was learned, I offer the following 25 recommendations for future work on this topic (Table 4) As per Table 4, these are organized into three categories: technical, institutional, and strategic funding. Technical recommendations are related to barriers to expertise or a knowledge gap, institutional recommendations are generally regarding community or institutional commitments or guidance, and funding recommendations related to financial barriers.

Table 4. Recommendations for technical, institutional, and strategic funding related to impacts to heritage from climate change.

Recommendations for Heritage Managers

Technical

1. Conduct research on site-specific impacts to heritage sites in the province.
2. Conduct additional studies to verify the number of sites determined to be vulnerable to impacts from climate change.
3. Update inventory of sites at risk where site forms do not conform to modern standards (e.g., hand-drawn maps, missing or inaccurate location data).
4. Ensure heritage inventories are searchable, and complete, and that consistent naming conventions are used.
5. Develop climate change prediction models that incorporate various heritage site types and environments.
6. Refine CanCoast and CCCS models to increase resolution and accuracy.
7. Update and expand provincial archaeological potential models so they can be used to identify previously unrecorded sites at risk of damage from climate change.
8. Develop models specific to predicting impacts to heritage sites from climate events (e.g., flooding, wind, wave, storm surge).
9. Create a template for preparing vulnerability assessments for individual sites that can be used by all heritage practitioners so consistent data are being recorded and compared.
10. Develop a monitoring system so that sites at risk can be adequately identified, studied, and documented before they are lost.
11. Develop a strategy to manage and monitor the impact of climate change on heritage sites based on Indigenous knowledge of past adaptation.

Institutional

12. Improve understanding of climate change and heritage management processes.
13. Ensure First Nations are involved in determining what heritage related climate change adaptation work is conducted and who is qualified to do the work.
14. Incorporate volunteers sponsored by a First Nation or qualified heritage specialists into the information sharing agreement for archaeological site data currently available on the Provincial Heritage Registry. Sharing of information would be limited to specific studies or survey areas.
15. Update governance and coordination of climate change response through engagement with affected communities.
16. Develop vulnerability risk assessments and adaptation plans on a local scale through engagement with community members.
17. Increase the urgency of protecting at-risk heritage by developing strategies to assess site vulnerability more accurately and mitigate and minimize impacts.
18. Develop guidance for heritage managers to address the impacts of climate change.
19. Make information on government decisions and responses to managing climate change impact on heritage more accessible to the public.

Strategic Funding

20. Create funding to develop modelling specific to impacts on heritage sites.
21. Develop and fund inventory and monitoring programs that include First Nations (e.g., Guardians[26]) to gather data to assess site conditions that cannot be determined through modelling.
22. Invest in technology, site protection, conservation, mitigation, and education.
23. Fund and conduct research on climate change impact on heritage sites in the province.

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[26] Guardian programs support First Nations as partners with the government and stakeholders to manage and protect resources, including heritage sites (Parks Canada 2022). Guardians do work to care for the land on behalf of their Nations (Indigenous Leadership Initiative 2021).

Recommendations for Heritage Managers
24. Make funding and resources available to evaluate heritage sites determined to be most vulnerable to climate change. 25. Reduce cost of response by organizing and training various volunteers to assist with monitoring and salvage work conducted under the direction of First Nations Guardians or heritage practitioner.

6.1.1. Technical Recommendations

Standards developed by Canada's Historic Places (2010:98) identify that sites should be kept in situ unless unavoidable conflicts or natural impacts threaten them. Heritage managers are used to the idea that minimizing disturbance to heritage by keeping it in situ will aid in preservation. However, climate change could increase the frequency and severity of risk events such as wildfires or landslides that could damage or destroy sites that are normally safe left in place. All sites will not be adversely affected by climate change, but some may be disproportionately affected. In particular, wet site environments are extremely fragile, and any changes to them would most likely have a greater detrimental effect on organic materials contained within them than on other types of sites (Fenger-Neilsen et al. 2020:1281; Ramseyer 2012:651-652). In addition, sites located along the coastline would be more susceptible to sea-level rise and severe weather events. Pest infestations and wildfires could damage sites in forested environments. More information is needed to determine how climate change could impact sites in the province. A better estimate of the number of sites affected is needed as the results of this study were based on incomplete or, in some cases, outdated or inaccurate site data. The provincial register also needs to be checked for sites that do not conform to modern standards of recording and be updated through either site revisits or other means. The registry should also be assessed to ensure inventories are searchable, complete, and that consistent naming conventions are used. This could assist future researchers needing to locate site specific data.

New models are needed that incorporate how heritage sites, especially buried sites, respond to changes in temperature, precipitation, acidity, groundwater fluctuation, and other environmental factors. Including potential models in future analysis could help identify areas with high potential to locate archaeological sites that climate changes could impact. Prediction models that include climate change effects and archaeological potential for various biogeoclimatic zones across the province would benefit heritage managers. New models should also encompass a spectrum of weather, climate-linked secondary impacts, and how various cultural sites and materials react to these changes (Carroll and Aarrevaara 2018:1; Sesana et al. 2021:20).

The CanCoast and CCCS models need to be refined to increase resolution and accuracy to better predict impacts to heritage. The CanCoast model should be updated to include more indices (e.g., flood, sea-level rise, groundwater penetration, and existing engineered protection such as seawalls and dykes). Also, updated models should visually represent the sensitivity area more accurately by capturing the extent of areas that could be inundated by sea-level rise. These data could also be used as a baseline for the development of models specific to predicting impacts to heritage sites from climate events such as flooding or extreme weather events. For areas where there are no documented sites, site potential models could be used to identify areas of potential that are at risk. The province has developed several models, but many are out of date and the coverage needs to be expanded to cover the entire region.

My study results indicate that thousands of sites may be vulnerable to climate change by the end of the century. Standard procedures for assessing and mitigating impacts on a site must be updated to reflect predicted climate change modelling results to prevent the loss of vital information about the past. Studies on climate change in the province have been mainly reactive (e.g., response to MPB, wildfires, flooding). In addition to dealing with emergencies as they arise, hertiage managers should also be able to plan proactively. Heritage practitioners can reduce or mitigate impacts impossible to control during emergencies by developing management plans, monitoring, and mitigation before disasters strike. Part of proactive planning is to develop vulnerability assessments for individual sites that can be used by heritage managers to consistently record and predict the vulnerability of sites. Assessments need to be standardized so that the information can be easily compared and queried. Using these assessments, a system should be developed to prioritize sites most vulnerable to impacts of climate change.

Many of these sites are fragile; all are non-renewable and of great significance to First Nations and local communities. Sites that are prioritized may need either mitigation or monitoring. To prevent the loss of at-risk sites, a monitoring and documentation system needs to be established and implemented through collaboration with affected First Nations and the government. Decisions regarding the prioritization, monitoring and mitigation of sites should involve First Nations and local communities and, where appropriate, draw on Indigenous knowledge and experience. Developing community-based archaeology programs using partnership models like the one established in Western Australia, where First Nations communities, archaeologists, and other heritage managers “employ mutually acceptable research agendas, work practices, and interpretive frameworks” (Mitchell et al. 2013:30) to manage heritage sites could help to involve and empower Nations. Not only can community-based archaeology programs guide the management of sites impacted by global warming they can also recommend how to manage sites in a way that respects Indigenous people’s traditions and cultural practices (Hollowell and Nicholas 2009:141). Guardians in British Columbia enforce Indigenous laws, promote Indigenous traditional knowledge and cultural heritage, and assess, conserve, and protect resources (Coastal First Nations Great Bear Initiative 2022:68). Supporting and funding Indigenous led programs such as Guardians not only contribute to better monitoring and management of heritage at risk of impact by climate change, but aspects could help to bring the province into alignment with goals set out in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP[27]), the Declaration of the Rights of Indigenous Peoples Act (DRIPA[28]), and the Truth and Reconciliation Commission[29] calls to action (Coastal First Nations Great Bear Initiative 2022:68).

6.1.2. Institutional Recommendations

Heritage sites provide an opportunity to educate and engage the public regarding the impacts of climate change in general, as well as the risk to and vulnerability of

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[27] United Nations Declaration of Indigenous People was adopted by Canada in 2016 (Government of Canada 2021c).

[28] Declaration of the Rights of Indigenous Peoples Act brought UNDRIP and the Calls to Action from the Truth and Reconciliation Commission into alignment with the laws of British Columbia and allowed for the provincial government to implement an action plan and to better collaborate with Indigenous governments (Government of British Columbia 2022).

[29] The Truth and Reconciliation Commission called on all levels of government in Canada to implement 94 actions related to the past and ongoing impacts the Indian Residential School system had (Government of Canada 2021d).

heritage (Markham 2017:10; Nimura et al. 2017:3). There is a need to increase education efforts to make people aware of the importance of British Columbia's heritage and the impacts of global warming. First Nations, the provincial heritage regulator, professional associations, and higher education institutions could all play a role in increasing awareness and providing practical hands-on training for heritage managers, professionals, and stewards.

Protecting valued heritage sites from future changes in climatic conditions, particularly extreme weather, or climate risk events (e.g., wildfires, floods), will require a shift from reactive to proactive adaptation. This can include the development of management plans and strategies for assessing potential for unregistered sites and prioritizing the most valuable and vulnerable sites. Once a threat has been identified, an assessment of the vulnerability of specific sites or potential areas should be made to understand the baseline conditions better. This work should be done by First Nations and local communities as well as on regional, provincial, and federal levels.

First Nations and local communities must be involved in heritage-related climate change adaptation decision making. Moreover, First Nations must be able to determine who is most capable of caring for their ancestors' ancient places and belongings (Lyons et al., 2022).England's CITiZAN and Scotland's SCAPE programs[30] are run by citizen scientists or heritage specialists from local areas to monitor, record, and sometimes mitigate sites threatened by coastal erosion (Dawson et al. 2019:8281-8282). These programs use public participation to complete the work with oversight from the specialist (Jensen 2017:134; Sesana et al. 2018:16). Rather than using the traditional model of having government, academics, and professionals manage heritage, these programs engage community members who assist with site prioritization, development, and implementation work plans (Dawson et al. 2019:8281). UNESCO (2007:30) argued that for adaptation strategies to be successful, it is essential to involve local communities in investigating and managing climate impacts on sites. Laws in British Columbia restrict who can conduct heritage work with access to archaeological information is provided to First Nations, government agencies, professional archaeologists, and accredited

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[30] The SCAPE (Scotland's Coastal Archaeology and the Problem of Erosion) program largely involved professional archaeologist to initially survey the coast and work with community groups to lead monitoring and mitigation efforts to salvage sites being impacted by global warming (Dawson et al. 2019:8281, Dawson et al. 2017:26-27).

researchers (BC Archaeology Branch 2019:1; Pokotylo and Mason 2010:9). Legally not being able to share site information with the public may hinder the involvement of volunteers to assist with work related to climate change adaptation such as excavations or monitoring programs (Nimura 2017:4). However, these laws do not necessarily restrict the involvement of Indigenous people in the protection and management of heritage sites within their lands (Bell and Lazin 2022:34-36). First Nations, however, do not have control over who is able to conduct heritage work on provincial lands, as the government of British Columbia directs this work under the HCA.

Under UNDRIP and DRIPA Indigenous people have the right to maintain, control, and protect their archaeological and historical places and belongings (Schaepe et al. 2020:53). Changes to the British Columbia HCA are underway to align with UNDRIP and DRIPA (Lyons et al. 2022). Currently, under Section 12.3(1)(d) of the HCA, the minister may order a heritage inspection or investigation of a heritage property that could be subject to alteration by natural or human causes such as climate change. However, there are no requirements to monitor or mitigate alterations climate change may cause to heritage sites. It is the government's role to decide when to order work to investigate or inspect impacts from climate change, as they did in response to the 2017-2018 wildfires. Although the wildfire work was conducted in cooperation with First Nations, it was funded by the provincial government and conducted under an HCA permit. Changes to the HCA should not only clarify what protection should be extended to sites threatened by climate change, but it should also formalize First Nations' rights to choose how work is conducted and by whom.

One benefit of climate risk events like wildfires is the exposure of previously unrecorded sites, adding to the knowledge of the past when new sites are recorded (Hammond 2018). However, opportunities are lost when conducting work in the aftermath of severe weather or disasters. Identifying vulnerable sites using climate change models can help prioritize where work is needed before it is too late. This may include developing a more proactive and focussed management approach to allow more time to consider intervention benefits, plan inventory or mitigation activities, and collect resources. Such a strategy could also facilitate shared decision-making and collaborative management (Liepe et al. 2015:409; Schaepe et al. 2020:25). Government needs to be more open regarding the management of climate change impacts to heritage. Guidance documents, vulnerability assessments, costs, available resources should be easily accessed. If they have not been developed, then they should be with participation of affected communities.

6.1.3. Strategic Funding Recommendations

My study demonstrates that the adverse effects of climate change are predicted to increase in areas for many registered sites across the province. As more people are affected, the cost of adaptation may rise, and competition for funds to pay for heritage projects and maintain heritage sites could intensify (Cassar 2005:33,36,63). Consulting with affected communities early, identifying, and prioritizing work on significant sites, and establishing monitoring and volunteer programs in the present can make a huge difference later, especially since few governments are able to fund the recording and preservation of all archaeological and historical information and objects that may be affected by climate change (Wragg et al. 2017:50).

Given the scale and magnitude of the issue, it is inevitable that climate change will result in the loss of some heritage sites. It is important to note that not all sites may be affected, and some types of sites are resilient to change (e.g., lithic scatters). Sites along the coast, wet sites, sites containing organic materials, wetlands, melting ice patches or glaciers, and forested sites vulnerable to pest infestations and wildfires may be disproportionately affected. Managing this loss and deciding on what can be saved or relinquished should be done through shared decision-making and a collaborative management process. Increased collaboration between heritage managers in different sectors (e.g., First Nations, academics, government, professionals) might allow more effective adaptation techniques to be implemented in a more holistic manner (Sesana et al. 2018:15). Collaboration between these sectors could be beneficial, allowing a coordinated and efficient response. However, it could also lead to slower emergency response times, relationship difficulties, or allocation of more funding to planning rather than action. Managing everyone’s expectations regarding developing and implementing strategies and policies related to site preservation might not be easy due to differing values and expectations (Nimura 2017:3). New regulations, guidelines, and funding are all be needed to identify and manage impacts. Coordinating the development of new regulations and guidelines and allocating funds require strong political commitment at all levels of government.

As climate events damage more sites each year, many government funding mechanisms will be used to conduct emergency response work. This may leave little funding or resources for a more proactive management approach. Lack of funding for heritage work unrelated to industry or development (e.g., logging, construction, mining) in British Columbia is a serious issue. In fact, First Nations have already raised concerns about a lack of funding to preserve heritage sites from the effects of climate change (British Columbia Heritage Branch 2021:3). There are alternatives to consider that could be more cost effective (e.g., Guardian Programs, volunteers, change in existing archaeological impact assessment and mitigation guidance).

With the adoption of the UNDRIP, DRIPA, and the Truth and Reconciliation Commission calls to action, it has been made clear that Indigenous peoples have rights over their cultural heritage (Supernant 2018:148). However, heritage management work often entails individuals acquiring specific credentials (e.g., university education) and experience to hold *Heritage Conservation Act* permits needed to work within sites on Provincial land (Supernant 2018:1485). For many First Nations, barriers around education, permitting, and funding need to be addressed to increase their involvement as leaders in the decision-making process regarding the response to future climate change impacts on heritage. Guardian programs help to reduce these barriers as they provide training and opportunities to promote the rights of Indigenous people to management of sites as equal partners with governments and industry (Parks Canada 2022). (Coastal First Nations Great Bear Initiative 2022:68)

First Nations across Canada, including British Columbia, are already involved in Guardian Programs[31] (Government of Canada 2021a, 2021b). According to a study of similar programs in Australia, for every dollar invested, ancillary cultural, social, and economic benefits were threefold (Indigenous Leadership Initiative 2021). Similar results were found in a study of Guardian Programs in the Northwest Territories (Indigenous Leadership Initiative 2021), Haida Gwaii, and along the south and central coasts of British Columbia (Coastal First Nations Great Bear Initiative 2022:5-6; Nanwakolas Council 2018). The Government of Canada has planned to contribute $100 million from 2021 to 2026 to the Indigenous Guardians pilot program. Additional support from

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[31] There is also a ranger program in Australia that is a precursor to the guardians that has been highly successful (Carmichael 2017b:162-164).

municipal and provincial governments, heritage practitioners, the public, and stakeholders could further strengthen the guardian program. Given the number of sites and size of the province, local community stewardship programs like CITiZAN and SCAPE could be beneficial for filling in the gaps in areas where guardians do not have a presence. Oversight of these programs could be coordinated between First Nations as stewards of the land, various levels of government, and individuals involved in community stewardship programs.

6.2. Future Research

This study faced two obstacles that could be overcome through additional research. First, some sites in the Provincial Heritage register had incorrect or missing data. Incomplete data meant several sites could not be compared to the climate modelling to identify potential impacts. The registry should be updated to increase the accuracy of predicting affected sites. Additionally, the registry should include specific impacts for modelled coastal sensitivity, temperature, and precipitation to more quickly identify sites that may be affected by global warming. Models that predict global warming can provide a general idea of how sites may be affected, but by increasing model resolution, individual site impacts can be targeted more precisely. Also, the coastal sensitivity modelling needs to include geospatial information for the total area predicted to be impacted (e.g., flood area). The second limitation is the gap in research to identify climate change impacts on sites in the province and which site types are most vulnerable. Upgrading models, datasets, and additional research on on-site impacts would take significant effort, well beyond the scope of this thesis.

Using the information in this thesis to spread awareness that British Columbia’s heritage could be at risk may help to inspire future research. I plan to disseminate the results by distributing copies of my thesis to relevant provincial agencies, First Nations, and First Nation organizations, preparing a summary paper to present at conferences, publishing information online, and submitting papers to academic journals or magazines. I will also make the results of my research available to researchers and heritage managers. I plan to create an online search tool that allows site Borden numbers to be used to search modelled impacts on sites. Due to restrictions on sharing site location data with the public, the search result would be limited to the site number, minimum temperature, maximum temperature, summer, winter, and average precipitation, and coastal sensitivity for the timesteps presented in the results section. By providing this knowledge, I hope that heritage managers will consider climate impacts when planning their work, in study recommendations, and site form updates for the consideration of future researchers.

6.3. Concluding Remarks

In recent years, extreme weather events in British Columbia and elsewhere have highlighted the urgency of climate action. Unprecedented heat, raging wildfires, catastrophic landslides, and flooding have damaged an unknown number of sites and tested the resiliency of all people who value heritage and those working in the heritage field. The trend in climate change predictions for the upcoming century is one of progressively increasing impacts on sites across almost every environment in the province. The threat of climate change to British Columbia's heritage needs to be addressed more aggressively. Our opportunity to manage effects may only last until other issues threatening everyone's daily lives take precedence. From the information reviewed, I do not believe heritage managers in the province are fully ready for the impact climate change will have on sites. A coordinated response to heritage management is needed sooner rather than later.

References

Agapiou, A., V. Lysandrou, D. Alexakis, K. Themistocleous, B. Cuca, A. Argyriou, A. Sarris, and D.G. Hadjimitsis
2015 Cultural Heritage Management and Monitoring Using Remote Sensing Data and GIS: The Case Study of Paphosarea, Cyprus, *Computers, Environment and Urban Systems*, 54, 230–239.

Aird, Karen, Gretchen Fox, and Angie Bain
2019 Recognizing and Including Indigenous Cultural Heritage in B.C. Electronic document, https://fpcc.ca/wp-content/uploads/2020/09/FPCC-ICH-Policy-Paper-EN-200825-WEB.pdf, accessed on March 16, 2022.

Allan L. Carroll, Steve W. Taylor, Jacques Régnière, and Les Safranyik
2003 Effects of Climate Change on Range Expansion by the MPB in British Columbia. Electronic document, https://d1ied5g1xfgpx8.cloudfront.net/pdfs/25051.pdf, accessed on November 24, 2020.

Anderson, David G., Thaddeus G. Bissett, Stephen J. Yerka, Joshua J. Wells, Eric C. Kansa, Sarah W. Kansa, Kelse Noack Myers, R. Carl DeMuth, and Devin A. White
2017 Sea-level Rise and Archaeological Site Destruction: An Example from the Southeastern United States Using DINAA (Digital Index of North American Archaeology). *PloS ONE* (12)11:1-25.

Auditor General of British Columbia
2018 Managing Climate Change Risks: An Independent Audit. Electronic document, https://www.bcauditor.com/sites/default/files/publications/reports/Climate_Change_FINAL_0.pdf, accessed on November 30, 2021.

Augustin, Colette (editor)
2007 Climate Change and World Heritage: Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist State Parties to Implement Appropriate Management Response. Electronic document, https://whc.unesco.org/document/8977, accessed on November 14, 2021.

Bell, Catherine, and Sarah Lazin
2022 A Selected Review of Federal and Provincial Legislation Implicating Indigenous Heritage in British Columbia. Electronic document, https://fpcc.ca/wp-content/uploads/2022/04/FPC-004-Review-of-Federal-and-Provincial-Legislation-WEB-SPREADS.pdf, accessed on November 16, 2022.

Benlloch, Pau Olmos, Elias Lopez-Romero, and Maria-Yvane Daire
2017 Chapter 9. Coastal Erosion and Public Archaeology in Brittany, France: Recent Experiences From the AleRT Project. *In Public Archaeology and Climate Change*, edited by Tom Dawson, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.81-89. Oxbow Books, Oxford.

Boethius Adam, Mathilda Kjällquist, Ola Magnell, and Jan Apel
2020 Human Encroachment, Climate Change and the Loss of Our Archaeological Organic Cultural Heritage: Accelerated Bone Deterioration at Agerod, A Revisited Scandinavian Mesolithic Key-Site in Despair. *PloS ONE* 15(7):1-23.

Bornhold, Brian D.
2008 Projected Sea-Level Changes for British Columbia in the 21st Century. Electronic document, https://www.retooling.ca/_Library/docs/Projected_BC_Sea_Level_Change_2008.pdf, accessed on December 7, 2020.

British Columbia Archaeology Branch
1996 *Heritage Conservation Act* [RSBC 1996] Chapter 187. Electronic document, https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96187_01, accessed on July 14, 2022.

2001 Culturally Modified Trees of British Columbia A Handbook for the Identification and Recording of Culturally Modified Trees. Electronic document, https://www.for.gov.bc.ca/hfd/pubs/Docs/Mr/Mr091/cmthandbook.pdf, accessed on November 29, 2020.

2017 Site Form Guide. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/archaeology/forms-publications/archaeology_site_form_guide.pdf, accessed on November 18, 2020.

2019 Archaeological Information Sharing Agreement. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/archaeology/forms-publications/archaeological_information_sharing_agreement.pdf, accessed on July 14, 2022.

British Columbia Heritage Branch
2021 What We Heard Outcomes of Provincial Engagement on Cultural Heritage. Electronic document, https://www2.gov.bc.ca/assets/gov/british-columbians-our-governments/our-history/historic-places/documents/culturalheritagepolicy_final.pdf, accessed on March 16, 2022.

British Columbia Ministry of Community Development
n.d. History of MPB Infestation in BC. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/history_of_the_mountain_pine_beetle_infestation.pdf, accessed on November 30, 2020.

British Columbia Ministry of Environment

n.d. Othello Tunnels. Electronic document, https://www.historicplaces.ca/en/rep-reg/place-lieu.aspx?id=18065, accessed on March 22, 2022.

2016 Indicators of Climate Change for British Columbia 2016 Update. Electronic document, https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/reporting/envreportbc/archived-reports/climate-change/climatechangeindicators-13sept2016_final.pdf, accessed on June 20, 2021.

British Columbia Ministry of Environment and Climate Change Strategy

2017 Climate Change Health Risks. Electronic document, https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/health/final_climate_change_and_health_backgrounder_overview.pdf, accessed March 7, 2022.

2019 Preliminary Strategic Climate Risk Assessment for British Columbia. Electronic document, https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/prelim-strat-climate-risk-assessment.pdf, accessed on August 20, 2019.

2021 Tahltan Land to be Protected in Partnership with Conservation Organizations, Industry and Province. Electronic document, https://news.gov.bc.ca/releases/2021ENV0025-000657, accessed on February 6, 2022.

British Columbia Ministry of Forests, Lands, and Natural Resource Operations

n.d. History of MPB Infestation in B.C. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/history_of_the_mountain_pine_beetle_infestation.pdf, accessed on November 23, 2020.

2013 *British Columbia Ministry of Forests, Lands, and Natural Resource Operations Climate Change Assessment Guide*. Victoria, BC.

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development

2011a Fire Perimeters – Historical. BC Wildfires Service, Victoria, DOI: https://catalogue.data.gov.bc.ca/dataset/22c7cb44-1463-48f7-8e47-88857f207702, accessed on November 23, 2020.

2011b Pest Infestation Polygons. Resource Practices, Victoria, DOI: https://catalogue.data.gov.bc.ca/dataset/450b67bb-02d5-4526-8bc0-ac7924125a1e, accessed on November 23, 2020.

British Columbia Ministry of Forests and Range Wildfire Management Branch
2009 Climate Change and Fire Management Research Strategy. Electronic document, https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/wildfire-status/governance/bcws_climate_change_research_strategy.pdf, accessed on March 10, 2022.

Brown, Kendrick J., Nicholas J. Hebda, Nicholas Conder, Karen G. Golinski, Brad Hawkes, Gerit Schoups, and Richard J. Hebda
2017 Changing Climate, Vegetation, and Fire Disturbance in a Sub-boreal Pine-Dominated Forest, British Columbia, Canada. *Canadian Journal of Forest Research* 47 (5):615-627.

Burleigh, Jennifer, Tim Ebata, Ken J. White, David Rusch and Harry Kope (editors)
2014 Field Guide to Forest Damage in British Columbia. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/forest-health-docs/field_guide_to_forest_damage_in_bc_web.pdf, accessed on November 29, 2020.

Busse, Matt D., Ken R. Hubbert, Gary O. Fiddler, Carol J. Shestak, and Robert F. Powers
2005 Lethal Soil Temperatures During Burning of Masticated Forest Residues. Electronic document, https://www.fs.fed.us/psw/publications/busse/psw_2005_busse002.pdf, accessed on November 30, 2020.

Canadian Heritage
2018 Government of Canada Survey of Heritage Institutions: 2017. Electronic document, https://www.canada.ca/en/canadian-heritage/corporate/publications/general-publications/about-survey-heritage-institutions/2017-report.html#a6, accessed on July 14, 2022.

2020 Government of Canada Survey of Heritage Institutions: 2019 . Electronic document, https://www.canada.ca/en/canadian-heritage/corporate/publications/general-publications/about-survey-heritage-institutions/2019-report.html, accessed on July 14, 2022.

Canada’s Historic Places
2010 Standards and Guidelines for the Conservation of Historic Places in Canada. Electronic document, https://www.historicplaces.ca/media/18072/81468-parks-s+g-eng-web2.pdf, accessed on November 15, 2022.

Cannings, Richard, and Sydney Cannings
1999 *Geology of British Columbia a Journey Through Time.* Greystone Books, Vancouver.

2015 *British Columbia a Natural History of Its Origins, Ecology, and Diversity with a New Look at Climate Change*, 3rd ed. Greystone Books, Vancouver.

Carmichael, Bethune
2018 Supporting Indigenous Rangers Manage the Impacts of Climate Change on Cultural Sites. PhD thesis, Philosophy Department, Charles Darwin University, Sydney.

Carmichael, Bethune, Greg Wilson, Ivan Namarnyilk, Sean Nadji, Sally Brockwell, Bob Webb, Fred Hunter, and Deanne Bird
2017a Local and Indigenous Management of Climate Change Risks to Archaeological Sites. *Mitigation Adaptation Strategies for Global Change.* 23(2):231-255.

Carmichael, Bethune, Greg Wilson, Ivan Namarnyilk, Sean Nadji, Jacqueline Cahill, Sally Brockwell, Bob Webb, and Deanne Bird
2017b Chapter 17. Australian Indigenous Rangers on Managing the Impacts of Climate Change on Cultural Heritage Sites. *In Public Archaeology and Climate Change*, edited by Tom Dawson, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.162-174. Oxbow Books, Oxford.

Carroll, Allan L., Steve W. Taylor, Jacques Regniere, and Les Safranyik,
2003 Effect of Climate Change on Range Expansion by the Mountain Pine Beetle in British Columbia. *The Bark Beetles, Fuels, and Fire Bibliography*. Paper 195. Electronic document, https://ceaa acee.gc.ca/050/documents_staticpost/cearref_21799/2876/schedule_e.pdf, accessed on September 9, 2021.

Carroll, Paul, and Eeva Aarrevaara
2018 Review of Potential Risk Factors of Cultural Heritage Sites and Initial Modelling for Adaptation to Climate Change. *Geosciences* 8(9):1-10.

Cassar, JoAnn
2016 Climate Change and Archaeological Sites: Adaptation Strategies. In *Cultural Heritage from Pollution to Climate Change*, edited by Roger-Alexandre Lefèvre and Christina Sabbioni, pp. 119-128. Centro Universitario Europeo per i Beni Culturali, Ravello.

Cassar, May
2005 Climate Change and the Historic Environment. Electronic document, https://discovery.ucl.ac.uk/id/eprint/2082/1/2082.pdf, accessed on February 16, 2022.

Clarke, Keith
1990 *Analytical and Computer Cartography*. Prentice-Hall Inc., Englewood Cliffs

Coastal First Nations Great Bear Initiative
2022 Coastal Guardian Watchmen: Stewarding the Coast for All A Case for Investment. Electronic document, https://coastalfirstnations.ca/wp-content/uploads/2022/07/CFN-Case-for-Investment-Report.pdf, accessed on November 14, 2022.

Cohen, Jenny
2019 Sgang Gwaay Storm Damage Archaeological Response 2019. Electronic document, https://static1.squarespace.com/static/5fb1f4e2211ab272daefda8a/t/5fcc56f05d2e6f3bda32a845/1607227324168/SGang-Gwaay-archaeology-Aug-2019.pdf, accessed on March 3, 2022.

Daly, Cathy
2011 Climate Change and the Conservation of Archaeological Sites: A Review of Impacts Theory. *Conservation and Management of Archaeological Sites* 13(4):293-310.

2014 A Framework for Assessing the Vulnerability of Archaeological Sites to Climate Change: Theory, Development, and Application. *Conservation and Management of Archaeological Sites* 16(3):268-282.

Daust, Dave
2013 Climate Change in BC. Electronic document, https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/applied-science/2a_va_bc-climate-change-final-aug30.pdf, accessed on March 21, 2022.

Dawson, Tom, Joanna Hambly, Alice Kelley, William Lees, and Sarah Miller
2019 Coastal Heritage, Global Climate Change, Public Engagement, and Citizen Science. *Proceedings of the National Academy of Sciences* 117(15):8280-8286.

Dawson, Tom, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire (editors)
2017 *Public Archaeology and Climate Change*. Oxbow Books, Oxford.

Deal, Krista
2012 Chapter 4: Fire Effects on Flaked Stone, Ground Stone, and Other Stone Artifacts. In *Wildland Fire in Ecosystems: Effects of Fire on Cultural Resources and Archaeology*, Volume 42, edited by Kevin C. Ryan, Ann Trinkle Jones, Cassandra L. Koerner, Kristine M. Lee, pp. 97-11. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Dickson-Hoyle, Sarah, and Char John
2021 *Elephant Hill: Secwépemc Leadership and Lessons Learned from the Collective Story of Wildfire Recovery. Secwepemcúl̓ecw Restoration and Stewardship Society.* Electronic document, https://www.srssociety.com/docs/elephant_hill_-_secw%C3%A9pemc_leadership_and_lessons_learned.pdf, accessed on May 1, 2022.

Dyok, Rebecca
2020 River Valley Flooding Destroys Archaeological Sites, Uncovers Others. Williams Lake Tribune May 12, Electronic document, https://www.wltribune.com/news/river-valley-flooding-destroys-archaeological-sites-uncovers-others/, accessed on June 16, 2021.

Eldridge, Morley
1997 The Significance and Management of Culturally Modified Trees. Electronic document, https://iaac-aeic.gc.ca/050/documents_staticpost/cearref_3394/hearings/SM03.pdf, accessed on November 30, 2020.

Fatorić, Sandra, and Erin Seekamp
2019 Knowledge Co-Production in Climate Adaptation Planning of Archaeological Sites. *Journal of Coastal Conservation* 23:689-698.

Fenger-Nielsen R, B. Elberling, A. Kroon, A. Westergaard-Nielsen, H. Matthiesen, H. Harmsen, C.K. Madsen, M. Stendel, and J. Hollensen
2020 Arctic Archaeological Sites Threatended by Climate Change: A Regional Multi-Threat Assessment of Sites in South-West Greenland. *Archaeometry* 62(6):1280-1297.

Fladmark, Knut R.
1985 *Glass and Ice: The Archaeology of Mt. Edziza.* Archaeology Press, Simon Fraser University, Burnaby.

Foreman M.G.G., W. Callendar, D. Masson, J. Morrison, and I. Fine
2014 A Model Simulation of Future Oceanic Conditions along the British Columbia Continental Shelf. Part. II: Results and Analyses. *Atmosphere-Ocean* (52)1:20-38.

Forino, Giusepe, Jamie MacKee, and Jason von Meding
2016 A Proposed Assessment Index for Climate Change-Related Risk for Cultural Heritage Protection in Newcastle (Australia). *International Journal of Disaster Risk Reduction* 19:235-248.

Friesen, T. Max
2018 Archaeology and Modern Climate Change. *Canadian Journal of Archaeology* 42:28–37.

Friggens, Megan M., Rachel A. Loehman, Connie I. Constan, and Rebekah R. Kneifel
2021 Predicting Wildfire Impacts on the Prehistoric Archaeological Record of the Jemez Mountain, New Mexico, USA. *Fire Ecology (17)18:1-19.*

Government of British Columbia
2022 Declaration on the Rights of Indigenous Peoples Act. Electronic document, https://www2.gov.bc.ca/gov/content/governments/indigenous-people/new-relationship/united-nations-declaration-on-the-rights-of-indigenous-peoples, accessed on August 21, 2022.

Government of Canada
2019 Canada's Scientists Conclude That Human-Induced Climate Change had a Strong Impact on Forest Fires in British Columbia. Electronic document, https://www.canada.ca/en/environment-climate-change/news/2019/01/canadas-scientists-conclude-that-human-induced-climate-change-had-a-strong-impact-on-forest-fires-in-british-columbia.html, accessed on November 24, 2020.

2020a CanCoast-Coast Materials Version 2.0. Electronic document, https://open.canada.ca/data/en/dataset/73714ed4-a795-a7ae-7e93-36100ce7c242, accessed on Nov 20, 2020.

2020b Statistically Downscaled Climate Scenarios. Electronic document, https://climate-change.canada.ca/climate-data/#/downscaled-data, accessed on November 15, 2020.

2021a Indigenous Guardians Pilot. Electronic document, https://www.canada.ca/en/environment-climate-change/services/environmental-funding/indigenous-guardians.html, accessed on July 14, 2022.

2021b Indigenous Guardians Pilot Map. Electronic document, https://www.canada.ca/en/environment-climate-change/services/environmental-funding/indigenous-guardians/map.html, accessed on July 14, 2022.

2021c Government of Canada introduces legislation respecting the United Nations Declaration on the Rights of Indigenous Peoples. Electronic document, https://www.canada.ca/en/department-justice/news/2020/12/government-of-canada-introduces-legislation-respecting-the-united-nations-declaration-on-the-rights-of-indigenous-peoples.html, accessed on August 21, 2022.

2021d Truth and Reconciliation Commission of Canada. Electronic document, https://www.rcaanc-cirnac.gc.ca/eng/1450124405592/1529106060525, accessed on August 21, 2022.

Hamann, Andreas, and Tongli Wang

2006 Potential Effects of Climate Change on Ecosystem and Tree Species Distribution in British Columbia. *Ecology* 87(11):2773-2786.

Hamilton, Ron, John Watt, Johan Tidbald, and Vladimir Kucera

2009 *The Effects of Air Pollution on Cultural Heritage.* Springer. New York.

Hammond, Joanne

2018 After the Blaze: Archaeology and Wildfires Recovery. Electronic document, http://republicofarchaeology.ca/digit/2019/10/19/after-the-blaze-archaeology-and-wildfire-recovery, accessed on November 30, 2020.

Hamrick, Patty

2018 How Climate Change Could Destroy Thousands of Archaeological Sites – Pacific Standard. Electronic document, https://psmag.com/environment/rising-tides-swallow-all-sites, accessed February 3, 2019.

Hangan, Margaret, Michael Lyndon, Connie Reid, Neil Weintraub, Brit Bettenson, Chris Ruff, Dave Gifford, Jeremy Haines, and Steward S. Robertson

2008 Wildland Fire Guidelines for Archaeologists on the Kaibab National Forest. Electronic document, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5126090.pdf, accessed on March 10, 2022.

Hare, Greg, Sheila Greer, Heather Jones, Rae Mombourquette, John Fingland, Mark Nelson, Jason Shorty, and Tip Evans
2011 The Frozen Past: The Yukon Ice Patches. Electronic document, https://emrlibrary.gov.yk.ca/Tourism/frozen-past-yukon-ice-patches-2011.pdf, accessed on March 13, 2022.

Hausfather, Zeke, Henri F. Drake, Tristan Abbott, and Gavin A. Schmidt
2020 Evaluating the Performance of Past Climate Model Projections. *Geophysical Research Letters* 47(1):1–10.

Hebda, Richard
1995 British Columbia Vegetation and Climate History with Focus on 6 KA. BP, *Geographie Physique et Quaternaire* 49(1):5-79.

Hebda, Richard J., Sheila Greer, and Alexander Mackie
2012 Teachings from Long Ago Person Found Highlights from the Kwäday Dän Ts'ìnchi Project. Electronic document, https://issuu.com/royalbcmuseum/docs/kdt_highlights, accessed on June 15, 2021.

Heilen, Michael, Jeffry H. Altschul, and Friedrich Lüth
2018 Modelling Resource Values and Climate Change Impacts to Set Preservation and Research Priorities. *Conservation and Management of Archaeological Sites* 20(4):261-284.

Hollesen, Jørgen, Martin Callanan, Tom Dawson, Rasmus Fenger-Nielsen, T. Max Friesen, Anne M. Jensen, Adam Markham, Vibeke V. Martens, Vladimir V. Pitulko, and Marcy Rockman
2018 Climate Change and The Deteriorating Archaeological and Environmental Archives of the Arctic. *Antiquity* 92(363):573-586.

Hollesen, Jørgen , Henning Matthiesen, and B. Elberling
2017 The Impact of Climate Change on an Archaeological Site in the Arctic. *Archaeometry* 59(6):1175-1189.

Hollowell, Julie and George Nicholas
2009 Using Ethnographic Methods to Articulate Community-Based Conceptions of Cultural Heritage Management. *Public Archaeology: Archaeological Ethnographies* 8(2-3):141-160.

Holtorf, Cornelius, and Troels Myrup Kristensen
2014 Heritage Erasure: Rethinking "Protection" and "Preservation". *International Journal of Heritage Studies* 21(4):313-317.

Hope, Graeme, Peter Jordan, Rita Winkler, Tim Giles, Mike Curran, Ken Soneff, and Bill Chapman
2015 Post-Wildfires Natural Hazards Risk Analysis in British Columbia, Land Mangement Handbook 69, Electronic document, http://www.llbc.leg.bc.ca/public/pubdocs/bcdocs2015_2/589588/lmh69.pdf, accessed on October 31, 2021.

Howard, A.J., K. Challis, J. Holden, M. Kincey, and D.G. Passmore
2005 The Impact of Climate Change on Archaeological Resources in Britain: A Catchment Scale Assessment. *Climate Change* 91:405-422.

Hugonnet, Romain, Robert McNabb, Etienne Berthier, Brian Menounos, Christopher Nuth, Luc Girod, Daniel Farinotti, Matthias Huss, Ines Dussaillant, Fanny Brun, and Andreas Kääb
2021. Accelerated Global Glacier Mass Loss in the Early Twenty-first Century. *Nature* 592(7856), 726–731.

ICF
2019 Strategic Climate Risk Assessment Framework for British Columbia Developed in progress toward a Strategic Climate Risk Assessment for British Columbia. Electronic document, https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/climate-risk-assessment-framework.pdf, accessed on February 15, 2021.

Indigenous Leadership Initiative
2021 Indigenous-led Conservation: IPCAs & Guardians. Electronic document, https://www.ilinationhood.ca/publications/backgrounderipcasguardians, accessed on November 14, 2022.

Intergovernmental Panel on Climate Change (IPCC)
2014 Climate Change 2014: Summary for Policy makers. Climate Change 2014: Impacts, Adaptation and Vulnerability – Contributions of the Working Group II to the Fifth Assessment Report. Electronic document, https://www.ipcc.ch/report/ar5/wg2/, accessed on March 5, 2022.

2018 Global Warming of 1.5°C An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Electronic document, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf, accessed on December 6, 2020.

2022 Climate Change 2022 Impacts, Adaptation and Vulnerability Summary of Policy Makers – Working Group II Contribution to the Sixth Report of the Intergovernmental Panel on Climate Change. Electronic document, https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf, accessed on March 5, 2022.

International Union for Conservation of Nature World Heritage
2020 Kluane / Wrangell-St Elias / Glacier Bay / Tatshenshini-Alsek 2020 Conservation Outlook Assessment. Electronic document, https://worldheritageoutlook.iucn.org/ar/node/971/pdf, accessed on June 15, 2021.

Ives, Timothy H., Kevin A. McBride, and Joseph N. Waller
2018 Surveying Coastal Archaeological Sites Damaged by Hurricane Sandy in Rhode Island, USA, *The Journal of Island and Coastal Archaeology* 13(1):66-89.

Jensen, Anne M.
2017 Chapter 14. Threatened Heritage and Community Archaeology on Alaska's North Slope. In *Public Archaeology and Climate Change*, edited by Tom Dawson, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.126-137. Oxbow Books, Oxford.

Jones, Anne Trinkle, and Robert C. Euler
1986 Effects of Forest Fires on Archaeological Resources at Grand Canyon National Park. *North American Archaeologist* 7(3):243-254.

Keddie, Grant, and. And Earle Nelson
2005 An Arrow from the Tsitsutl Glacier, British Columbia. *Canadian Journal of Archaeology/Journal Canadien d'archéologie* 29(1):113-123.

Kelly, Alanna
2021 What Remains of the Othello Tunnels After the B.C. Storms. *North Shore News,* 2 December 2021.

Kibblewhite, Mark, Gergely Tóth, and Tamás Hermann
2015 Predicting the Preservation of Cultural Artefacts and Buried Materials in Soil. *Science of the Total Environment* 529(2015):249-263.

Kincey, Mark, Keith Challis, and Andy J. Howard
2008 Modelling Selected Implications of Potential Future Climate Change on the Archaeological Resource of River Catchments: An Application of Geographical Information Systems. *Conservation and Management of Archaeological Sites* 10(2):113–131.

Kirchmeier-Young, M. C., N.P., Gillett, F.W. Zwiers, A.J. Cannon, and F.S. Anslow
2019 Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season. *Earth's Future* 7: 2–10. Electronic document, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2018EF001050, accessed on November 24, 2020.

Klassen, Michael, Rick Budhwa, and Rudy Reimer/Yumk̲s
2009 First Nations, Forestry, and the Transformation of Archaeological Practice in British Columbia, Canada. *Heritage Management* 2(2):199–238.

Langley, David
2001 Determining the Effects of Prescribed Burning on Cultural Resources. Electronic document, https://www.frames.gov/documents/catalog/tfm/langley_%5Bunk%5D_TFM-15-347.pdf, accessed on February 18, 2022.

Larsson, Anton
2021 Landslides vs Archaeology: Case Studies of Site Loss and Emergency Fieldwork in Västra Götaland County, Sweden. *Current Swedish Archaeology* 29(1):183-205.

Lemmen, Donald S., Fiona J. Warren, Thomas S. James, and Colleen S.L. Mercer Clarke
2016 Canada's Marine Coasts in a Changing Climate. Electronic document, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/files/pdf/NRCAN_fullBook%20%20accessible.pdf, accessed on September 5, 2021.

Lettrari, Heike
2017 The Mountain Pine Beetle, Climate Change, and Scientists: Understanding Science's Responses to Rapid Ecological Change in Western Canada. Unpublished M.A. thesis, School of Environmental Studies, University of Victoria.

Liepe, Katharina J., Andreas Hamann, Pia Smets, Connor R. Fitzpatrick, and Sally N. Aitken.
2015 Adaptation of Lodgepole Pine and Interior Spruce to Climate: Implications for Reforestation in a Warming World. *Evolutionary Applications* 9:409-419.

Lipe, William D.
1974 A Conservation Model for American Archaeology. *Kiva* 39(3/4):213-245.

Lyons, Natasha, Roma Leon, Jasmine Peone, Sarah Hazell, Debbie Miller, Josh Dent, and Tanya Hoffmann
2022 Decolonizing Archaeology: Decolonizing CRM is About the Power to Decide. Electronic document, https://mydigitalpublication.com/publication/?m=16146&i=768625&view=articleBrowser&article_id=4385025&ver=html5, accessed on November 19, 2022.

Mackie, Quentin, Daryl Fedje, and Duncan McLaren
2010 Arrow from Tsitsutl Peak Glacier, Western B.C. Electronic document, https://qmackie.com/2010/03/27/arrow-from-tsitsutl-peak-glacier-western-b-c/, accessed on February 6, 2022.

Maio, C.V., A.M. Gontz, D.E. Tenenbaum, and E.P. Berkland
2012 Coastal Hazard Vulnerability Assessment of Sensitive Historical Sites on Rainsford Island, Boston Harbor, Massachusetts. *Journal of Coastal Research* 28(1A):20-33.

Manson, Gavin K., Nicole J., Couture, and Thomas S. James
2019 2.0: Data and Indices to Describe the Sensitivity of Canada's Marine Coasts to Changing Climate. Geological Survey of Canada Open File 8551 CanCoast. Electronic document, https://geoscan.nrcan.gc.ca/text/geoscan/fulltext/of_8551.pdf, accessed on November 1, 2020.

Markham, Adam
2017 Chapter 2. The Growing Vulnerability of World Heritage to Rapid Climate Change and the Challenge of Managing for An Uncertain Future. In *Public Archaeology and Climate Change*, edited by Tom Dawson, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.10-22. Oxbow Books, Oxford.

Matthiesen, Henning, Rasmus Fenger-Neilsen, Hans Harmsen, Christian Koch Madsen, and Jørgen Hollesen.
2020 The Impact of Vegetation on Archaeological Sites in the Low Arctic in Light of Climate Change. *Arctic 73 (2):1421-152.*

Meidinger, Del V., and Jim Pojar
1991 *Ecosystems of British Columbia*. Research Branch, Ministry of Forests, Province of British Columbia, Victoria.

Meyn, Andrea, Stephen W. Taylor, Mike D. Flannigan, Kirsten Thonicke, and Wolfgang Cramer
2009 Relationship Between Fire, Climate Oscillations, and Drought in British Columbia, Canada, 1920–2000. *Global Change Biology* 16:977–989.

Mitchell, Myles, David R. Guilfoyle, Ron Doc Reynolds, and Catherine Morgan
2013 Towards Sustainable Community Heritage Management and the Role of Archaeology: A Case Study from Western Australia. *Heritage & Society* 6(1):24-45.

Moore, R.D (Dan), David L. Spittlehouse, Paul H. Whitfield, and Kerstin Stahl
2010 Weather and Climate*,* In *B.C. Land Management Handbook: Compendium of Forest Hydrology and Geomorphology in British Columbia*, Vol. 1(66), edited by Robin G. Pike, Todd E. Redding, R.D. (Dan) Moore, Rita D. Winker and Kevin D. Bladon, pp. 47-84. On file at the British Columbia Ministry for Range, Victoria.

Murdock, Trevor Q., Stephen W. Taylor, Aquila Flower, Alan Mehlenbacher, Alvaro Montenegro, Francis W. Zwiers, Rene Alfaro, and David L. Spittlehouse
2013 Pest Outbreak Distribution and Forest Management Impacts In a Changing Climate in British Columbia. *Environmental Science & Policy* 26:75-89.

Nanwakolas Council
2018 Telling Us Where We Came From. Electronic document, https://nanwakolas.com/news/telling-us-where-we-came-from/, accessed on November 14, 2022.

National Research Council
2010 *Advancing the Science of Climate Change.* The National Academies Press, Washington.

Nicholas, George
2012 Toward an Anthropology of Wetland Archaeology: Hunter-Gatherers and Wetlands in Practice and Theory. In *The Oxford Handbook of Wetland Archaeology*, edited by Francesco Menotti and Aiden O'Sullivan, pp. 761-778. Oxford University Press, Oxford.

Nikiforuk, Andrew
2011 *Empire of the Beetle How Human Folly and a Tiny Bug are Killing North America's Great Forests*. Greystone Books, Vancouver.

Nimura, Courtney, Tom Dawson, Elias Lopez-Romero, and Marie Yvane Daire
2017 Chapter 1. Public Archaeology and Climate Change: Reflections and Considerations. In *Public Archaeology and Climate Change*, edited by Tom Dawson, Tom, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.1-9. Oxbow Books, Oxford.

Ohio University
2021 The Evolution of Portable GPS. Electronic document, https://onlinemasters.ohio.edu/blog/the-evolution-of-portable-gps/, accessed on November 15, 2022.

Oster, Elizabeth A., Samantha Ruscavage-Barz, and Michael L. Elliott
2012 The Effects of Fire on Subsurface Archaeological Materials. In *Wildland Fire in Ecosystems: Effects of Fire on Cultural Resources and Archaeology*. Volume 3, edited by Kevin C. Ryan, Ann Trinkle Jones, Cassandra L. Koerner, and Kristine M. Lee, pp.1-13. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Pacific Climate Impacts Consortium
n.d. Statistically Downscaled Climate Scenarios. Electronic document, https://pacificclimate.org/data/statistically-downscaled-climate-scenarios, accessed on March 23, 2022.

Parker, Scott
2017 *Let's Talk about Climate Change: Pacific Region.* Electronic document, http://parkscanadahistory.com/publications/lets-talk-about-climate-change/6-pacific-e.pdff, accessed on November 7, 2021.

Parks Canada
2019 Archaeology in a Burned Landscape: Nature Gives and Nature Takes Away. Electronic document, https://www.pc.gc.ca/en/pn-np/ab/waterton/nature/environment/feu-fire/feu-fire-kenow/blogue-blog/arch-1, accessed on November 30, 2020.

2022 Indigenous Connections. Electronic document, https://www.pc.gc.ca/en/culture/autochtones-indigenous/gardiens-guardians, accessed on July 30, 2022.

Perry, Jim, and Charlie Falzon
2014 World Heritage Paper Series N°37 Climate Change Adaptation for Natural World Heritage Sites a Practical Guide. Electronic document, file:///C:/Users/evabr/Downloads/publi_paper_series_37_en.pdf, accessed on March 1, 2022.

Pigott, Robin, and Bill Hume
2009 *Weather of British Columbia*. Lone Pine Publishing, Edmonton.

Pokotylo, David, and Andrew R. Mason
2010 Archaeological Heritage Resource Protection in Canada. In *Cultural Heritage Management: A Global Perspective*, edited by Phyllis Mauch Messenger and George S. Smith, pp.1-19. University Press of Florida, Gainesville.

Previtali, Mattia, Chiara Stanga, Thomas Molnar, Lore Van Meerbeek, and Luigi Barazzetti
2018 An integrated Approach for Threat Assessment and Damage Identification on Built Heritage in Climate-Sensitive Territories: The Albenga Case Study (San Clemente church). *Applied Geomatics* 10(2):485-499.

Province of British Columbia
n.d. Bark Beetle Management Guidebook. Electronic document, https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/forest-health/bark-beetles/bark_beetle_management_guidebook.pdf, accessed on November 15, 2021.

2015 British Columbia Zebra and Quagga Mussel Early Detection and Rapid Response Plan. Electronic document, http://www.llbc.leg.bc.ca/public/pubdocs/bcdocs2016/599270/prov_zqm_edrr_plan.pdf, accessed on February 28, 2022.

2020a Bark Beetles. Electronic document, https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/forest-pests/bark-beetles, accessed on November 29, 2020.

2020b Wildfires Season Summary. Electronic document, https://www2.gov.bc.ca/gov/content/safety/wildfires-status/about-bcws/wildfires-history/wildfires-season-summary, accessed on November 29, 2020.

2020c The 1999-2015 Mountain Pine Beetle Outbreak. Electronic document, https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/forest-pests/bark-beetles/mountain-pine-beetle/responding-to-the-1999-2015-outbreak, accessed on March 22, 2022.

Ramseyer, Denis
2012 Preservation Against Erosion: Protecting Lake Shores and Coastal Environments. In *The Oxford Handbook of Wetland Archaeology*, edited by Francesco Menotti and Aidan O'Sullivan, pp. 651-662. Oxford University Press, Oxford.

Reimer, Rudy
2015 Reassessing the role of Mount Edziza obsidian in northwestern North America. *Journal of Archaeological Science.* 2:418-426.

Rockman, Marcy, Marissa Morgan, Sonya Ziaja, George Hambrecht, and Alison Meadow

2016 Cultural Resources Climate Change Strategy. Washington, DC: Cultural Resources, Partnerships, and Science and Climate Change Response Program, National Park Service. Electronic document, https://www.nps.gov/subjects/climatechange/upload/NPS-2016_Cultural-Resoures-Climate-Change-Strategy.pdf, accessed on November 11, 2021.

Rodenhuis, D.R., K.E. Bennett, A.T. Werner, T.Q. Murdock, and D. Bronaugh

2009 Hydro-Climatology and Future Climate Impacts in British Columbia. Electronic document, https://www.researchgate.net/publication/263089147_Hydro-Climatology_and_Future_Climate_Impacts_in_British_Columbia, accessed on March 17, 2022.

Ryan, Kevin C., Ann Trinkle Jones, Cassandra L. Koerner, Kristine M. Lee, and Nelson Siefkin

2012 Effects of Fire on Cultural Resources—Introduction. In *Wildland Fire In Ecosystems: Effects of Fire on Cultural Resources and Archaeology* Volume 3, edited by Kevin C. Ryan, Ann Trinkle Jones, Cassandra L. Koerner, Kristine M. Lee, pp. 1-13. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.

Sabbioni C., M. Cassar, P. Brinblecombe, and R.A. Lefevre

2008 Vulnerability of Cultural Heritage to Climate Change. Electronic document, https://www.coe.int/t/dg4/majorhazards/activites/2009/ravello15-16may09/Ravello_APCAT2008_44_Sabbioni-Jan09_EN.pdf, accessed on February 11, 2022.

Schaepe, David M., George Nicholas, and Kierstin Dolata

2020 Recommendations for Decolonizing British Columbia’s Heritage-Related Processes and Legislation. First Peoples Cultural Council. Electronic document, https://fpcc.ca/wp-content/uploads/2020/12/FPCC-Decolonizing-Heritage-Processes-and-Legislation.pdf, accessed on November 28, 2021.

Sesana, Elena, Alexandre S. Gagnon, Chiara Bertolin JoAnne Cassar, and John J. Hughes

2018 Adapting Cultural Heritage to Climate Change Risks: Perspectives of Cultural Heritage Experts in Europe. *Geosciences* 8(305):1-23.

Sesana, Elena, Alexandre S. Gagnon, Chiara Ciantelli, JoAnne Cassar, and John J. Hughes

2021 Climate Change Impacts on Cultural Heritage: A Literature Review. *WIREs Climate Change* 12(4):1-29.

Shayegh, Soheil, Juan Moreno-Cruz, and Ken Caldeira

2016 Adapting to Rates Versus Amounts of Climate Change: A Case of Adaptation to Sea-Level Rise. *Environment Research Letters* 11(10):1-8.

Sinsky, Katherine A.
2020 Long-term Wildfires Impacts on Archaeological Sites and Survey Apache-Sitgreaves National Forest, Arizona. M.A. thesis, Department of Anthropology and Geography, Colorado State University, Fort Collins.

Smith, Dan J.
2000 Little Ice Age history of Tzeetsaytsul Glacier, Tweedsmuir Provincial Park, British Columbia. *Geographie Physique et Quaternaire* 54(2): 135-141.

Smith, Nicole, and ICLEI Canada
2020 *Considering Sea Level Rise and Cultural Heritage: A Resource for Municipalities. An Initiative from the Together for Climate Project*. ICLEI Canada, Toronto.

Spalding, Mark J.
2011 Perverse Sea Change: Underwater Cultural Heritage in the Ocean is Facing Chemical and Physical Changes. *Cultural Heritage and Arts Review* 2(1):12-16.

Spennemann, Dirk H.R.
2022 The Nexus between Cultural Heritage Management and the Mental Health of Urban Communities. *Land* 11(304):1-10.

Statistics Canada
2019 Estimates of the Direct Economic Impact of Culture in Western Provinces in 2017. Electronic document, https://hillstrategies.com/2019/06/19/estimates-of-the-direct-economic-impact-of-culture-in-the-western-provinces-in-2017/, accessed on July 14, 2022.

St. Amand, Frankie, Daniel H. Sandweiss, and Alice R. Kelley
2020 Climate-Driven Migration: Prioritizing Cultural Resources Threatened by Secondary Impacts of Climate Change. *Natural Hazards* 103:1760-1781.

Stefanyshen, Earl
2019 Microstratigraphic Protocol to Assess the Impact of Wildfires on Subsurface Archaeological Sites. M.A. thesis, Department of Archaeology
Faculty of Environment, Simon Fraser University, Vancouver.

Supernant, Kisha
2018 Reconciling the Past for the Future: The Next 50 Years of Canadian Archaeology in the Post-TRC Era. *Canadian Journal of Archaeology* 42(1):144-153.

Tahltan Central Government
2020 Annual Report 2020. Electronic document, https://tahltan.org/2020-annual-report/, accessed on June 16, 2021.

Turner, Nancy, and Helen Clifton
2009 "It's So Different Today": Climate Change and Indigenous Lifeways in British Columbia, Canada. *Global Environmental Change* 19:180–190.

United Nations
1992 United Nations Framework Convention on Climate Change. Electronic document, https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf, accessed on November 15, 2022.

United Nations Educational, Scientific, and Cultural Organization
2021 Twenty-third Session of the General Assembly of States Parties to the Convention Concerning the Protection of the World Cultural and Natural Heritage. Electronic document, https://whc.unesco.org/archive/2021/whc21-23GA-inf11-en.pdf, accessed on May 16, 2022.

United Nations Educational, Scientific, and Cultural Organization World Heritage Centre
2007 Climate Change and World Heritage Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist States Parties to Implement Appropriate Management Responses. Electronic document, https://whc.unesco.org/document/8977, accessed on May 23, 2022.

Union of Concerned Scientists
2018 Archaeologists Race Against Time to Save Sites from Climate Change. Union of Concerned Scientists. Electronic document, https://www.ucsusa.org/press/2018/archaeologists-race-against-time-save-sites-climate-change-0#.XFfbL6pKjIV, accessed February 3, 2019.

Watkins, Joe E., and John Beaver
2008 What Do We Mean by “Heritage”? *Heritage Management* 1(1):9-35.

Watt, John, Johan Tidbald, and Vladimir Kucera.
2009. *The Effects of Air Pollution on Cultural Heritage*. Springer, New York.

Watson, R.T., L.G. Meira Filho, E. Sanhueza, and A. Janetos
1992 Greenhouse Gases: Sources and Sinks. In *Climate Change 1992 The Supplementary Report to the IPCC Scientific Assessment.* edited by J.T. Houghton, B.A. Callander and S.K. Varney, pp. 23-47. University Press, Cambridge

Wayne, Graham
2013 The Beginner’s Guide to Representative Concentration Pathways. Electronic document, https://skepticalscience.com/docs/RCP_Guide.pdf, accessed on May 8, 2022.

Wheatly, David and Mark Gillings
2001 *Spatial Technology and Archaeology the Archaeological Applications of GIS*. Taylor & Francis, New York.

Whitewright, Julian
2012 Wreck Protect. Decay and Protection of Archaeological Wooden Shipwrecks – By Charlotte Gjelstrup Björdal and David Gregory. *International Journal of Nautical Archaeology* 41(2):474-475.

Whitney, Charlotte K., Tugce Conger, Nathalie C. Ban, and Romney McPhie
2020 Synthesizing and Communicating Climate Change Impacts to Inform Coastal Adaptation Planning. *FACETS* 5:704-737.

World Meteorological Organization
2019 WMO Provisional Statement on the State of the Global Climate in 2019, Electronic document, https://library.wmo.int/doc_num.php?explnum_id=10108, accessed on December 6, 2020.

Wragg, Eliott, Nathalie Cohen, Gustav Milne, Stephanie Ostrich, and Courtney Nimura
2017 Chapter 5. Community Recording and Monitoring of Vulnerable Sites in England. *In Public Archaeology and Climate Change,* edited by Tom Dawson, Courtney Nimur, Elías López-Romero, and Marie-Yvane Daire, pp.44-51. Oxbow Books, Oxford.

Wright, Jeneva
2016 Maritime Archaeology and Climate Change: An Invitation. *Journal of Maritime Archaeology* 11(3):255–270.

Wyatt, Glenda Joan
2015 Sea-Level Change in the Gulf Islands National Park Reserve, Southern British Columbia: Implications for the Interpretation of Nearshore Archaeological Features. M.Sc. thesis, Department of Social and Applied Sciences, Royal Roads University, Victoria.