EVOLVING COASTAL DEVELOPMENT PARADIGMS FOR A CHANGING CLIMATE:
VANCOUVER, VALPARAÍSO AND PLANNING FOR RESILIENCE

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ABSTRACT

The changing climate will have drastic and long lasting impacts on our communities and the built environment in which we live. Coastal cities of the west coast of the Americas in particular will face serious challenges from the effects of climate change as a result of both sea level rise and the potential increase in frequency and power of midlatitude cyclones. Valparaíso must navigate the test of developing a new paradigm for the evolution of its waterfront, while maintaining or reaffirming this crucial connection between city and sea. These challenges are global however, and our connected world means that cities need not face these tasks alone: opportunities exist for cities to reach out and learn from the experiences of others that are facing similar threats. The City of Vancouver has spent decades attempting to adapt their city to the changing climate, and now face the challenge of an encroaching ocean. By comparing the contexts and experiences of each city in through the paradigm of resilience thinking, we found that while Vancouver's experiences may not fully translate to the setting of Valparaíso, there are several steps Valparaíso can take immediately and for the future that will build resilience into their coastal border. By focusing on paradigm of adaptation rather than exploitation cities worldwide can adapt their waterfronts to be resilient in the face of an unpredictable environment.

We are called to be the
architects of the future, not its victims.

-Buckminster Fuller

I-INTRODUCTION

The next century of urban development will largely be defined by two global processes already well under way: climate change and urbanization. The intersection between these two forces gives rise to the question facing cities that is both timeless and yet uniquely and urgently of the moment: how to balance their increasing needs for space and amenities with the threat of natural hazards to which they are ever more exposed?

Since the middle of the 20th century, the world population has become steadily more urbanized, growing in number from 746 million in 1950 to 3.9 billion in 2014[1], marking the first time in history that more people worldwide live in urban areas than in rural areas. While the rural population has also increased along with the total world population, projections suggest that it reached its zenith in the early 2000's, and will gradually decline in the coming decades. [2]

This is a trend that shows no sign of abatement; urban population is expected to continue to rise by an estimated 2.5 billion people by the year 2050, at which point it will account for 2/3rds of the total world population[3]. With urbanization percentages (percent of total population living in urban areas) of 80% for South America and 81% for North America, the American continent is currently the worlds most urbanized.[4] The countries that fall under the purview of this paper (Chile, the United States, and Canada) are each among the highest urbanized in the continent, and each is projected to continue to urbanize by at least 4% by the year 2050 (Table 1.1).[5]

The urban growth trend can be attributed to two distinct demographic phenomena: increasing migration to cities and an ever-rising general population. The increase in population worldwide is worth examining

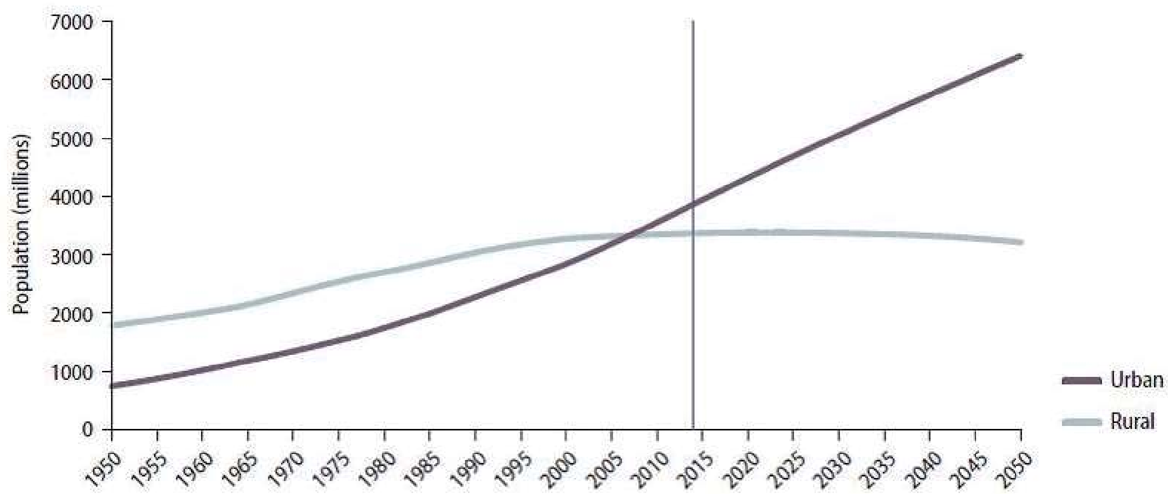


Image 1.1 *Worldwide rural vs. urban population 1950-2050 (projected)*

	Urbanization Pop Total (in millions)		Percentage of Population Urbanized	
	2014	2050	2014	2050
United States	262	350	81%	87%
Canada	29	39.5	82%	88%
Chile	16.8	19.5	89%	93%

Table 1.1 *Rural vs. urban populations in 2014 and 2050 (projected) for the three countries covered in this paper.*

in more detail, since its causes may not be immediately obvious and have repercussions in other realms of our study.

Contrary to what one may assume when seeing the steady rise in overall population, the fertility rate worldwide has actually decreased continually since the mid 1960's, when it reached its peak at 5.06 children per woman.[6] Rather, the greatest driver of the rising population has to do with the remarkable increase in life expectancy, especially in some of the world's most populous regions, over that same period. Average life expectancy from birth has grown apace with the total percent of urbanized population, and studies suggest that city living may part of the reason.[7] In the United States for example, rural and urban life expectancy rates have both risen in the past 50 years, but at increasingly different rates. While rural life expectancy from birth rose from 70.5 years in 1969-1971 to 76.7 years in 2005-2009, urban life expectancy rose from 70.9-79.1 during those same time periods, increasing the rural-urban disparity from 0.4 years to 2.4 years.[8] Even with declining birth rates, the incredible increases seen in life expectancy worldwide have unbalanced growth rates in urban areas compared to those in rural areas.

The other major contributing factor to city growth is migration. In these contexts we are primarily concerned with internal, rather than international, migration; the displacement of peoples from rural to urban areas within the borders of a single country. Reasons for migration are varied, but sociologists generally speak of them in terms of 'push' (repellant) or 'pull' (attractant) factors. Push factors, such as those listed in table 1.2, provide reasons for individuals or groups to leave rural areas, while pull factors present specific incentives for their relocation to urban areas.

Pull factors are varied and specific to individuals and groups, but perhaps the most compelling pull factor is the truly outsize role that modern cities play on the world stage. In economics, culture, religion, or any other international subject, cities offer unprecedented opportunities for innovation

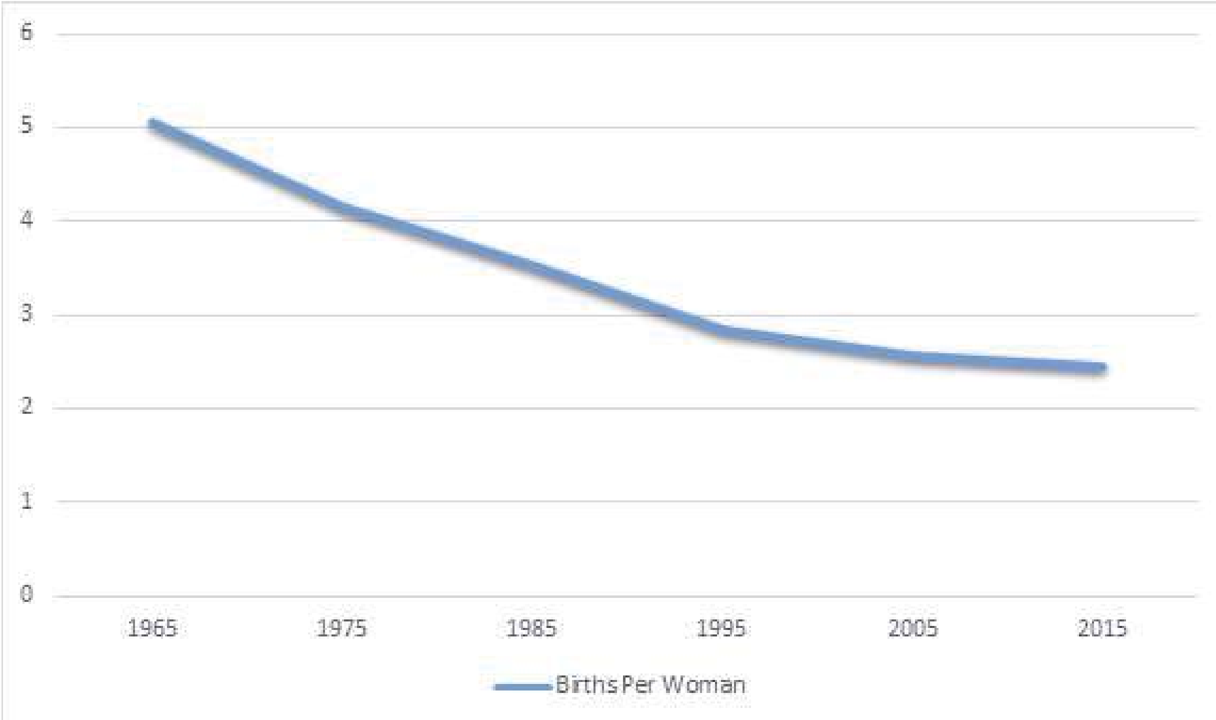


Image 1.2 *Births per woman worldwide 1965-2015. Source: World Development Indicators, The World Bank. Reproductive Health. September 18, 2017. http://wdi.worldbank.org/table/2.14#*

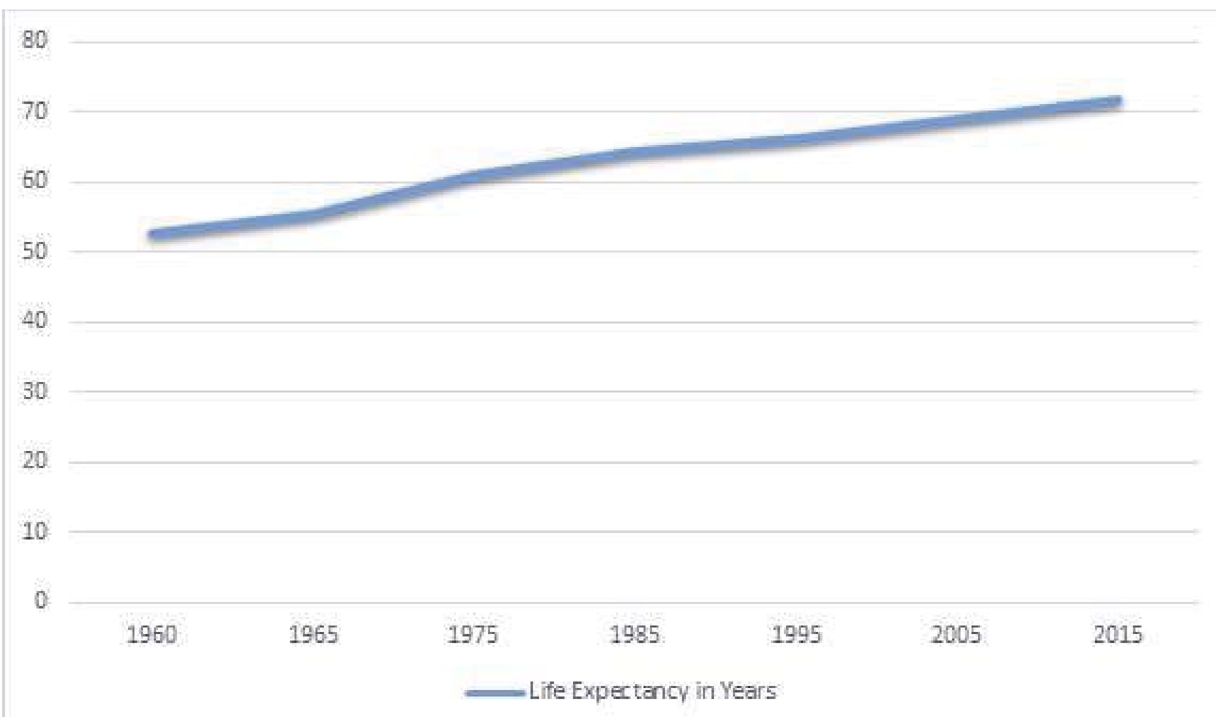


Image 1.3 *Worldwide life expectancy from brith1960-2015. Source: World Development Indicators, The World Bank. Reproductive Health. September 18, 2017. http://wdi.worldbank.org/table/2.14#*

Push Factors	Pull Factors
High Unemployment	Higher Standard of Living/Wages
Political/Religious Persecution	Labor Demand
Civil War	Political/Religious Freedom
Environmental Problems/Natural Hazards	Better Healthcare
Lack of Social Mobility	More Amenities/Opportunities

Table 1.2 *Common push and pull factors affecting migration, both internationally and internally*

and advancement. The largest and most connected of these can become what Saskia Sassen termed 'global cities', urban conglomerations that transcend nation state boundaries to link the world together through commerce and information.[9] The unlocking of the knowledge and experience concentrated in these global cities will be key to preparing urban areas worldwide for the shared threats they face. As our world becomes increasingly interconnected, the importance of the city continues to grow, and its role as a pull factor for emigrants will increase as well.

Push factors driving population towards cities are varied, but the most important factor for us to consider is the category of environmental problems and natural hazards, and how climate change will influence the other push factors in the list. As the top climate change official at the UN noted, "Climate change is the threat multiplier that worsens social, economic and environmental pressures, leading to social upheaval and even violent conflict."[10] As the effects of climate change continue to assert themselves worldwide, these push factors are exacerbated. Problems that rural areas suffer today like high unemployment and a lack of access to fresh water will only increase in severity with the changing climate. This suggests that even if the demographic component of urban growth were stagnant, the coming years would see

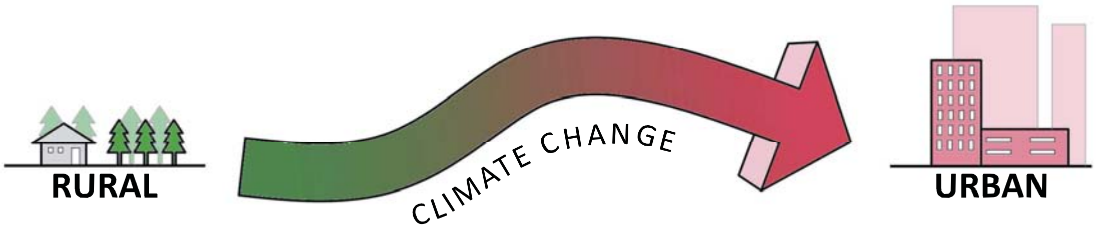


Image 1.4 *Climate change will exacerbate many existing push factors driving migration from rural to urban areas worldwide.*

Image 1.5 *The effects of climate change are varied and effect regions across the globe. Image sources, clockwise from left. 1)Associated Press. [Photo] 2018. Retrieved from https://www.wdtn.com/news/u-s-world/the-latest-northern-california-fire-whirl-reached-143-mph/1344670006. 2) Alamy Stock Photo, Robert Harding. [Photo] 2010. Retrieved from https://www.carbonbrief.org/climate-change-is-already-shifting-the-timing-of-european-floods-study-says. 3) Agence France Presse. [Photo] 2018. Retrieved from https://www.scmp.com/news/asia/article/1296077/japan-heatwave-kills-four. 4) Science Media Centre. [Photo] 2017. Retrieved from https://www.sciencemediacentre.co.nz/2017/09/04/leaked-mfe-report-coastal-hazards-climate-change-news. 5) Robert McSweeney. [Photo] 2018. Retrieved from https://www.carbonbrief.org/guest-post-climate-change-is-already-making-droughts-worse. 6)Reuters, M. Bazo. [Photo] 2018. Retrieved from https://www.dw.com/en/peru-floods-in-line-with-climate-change-models-says-climatologist-mojib-latif/a-38045642*

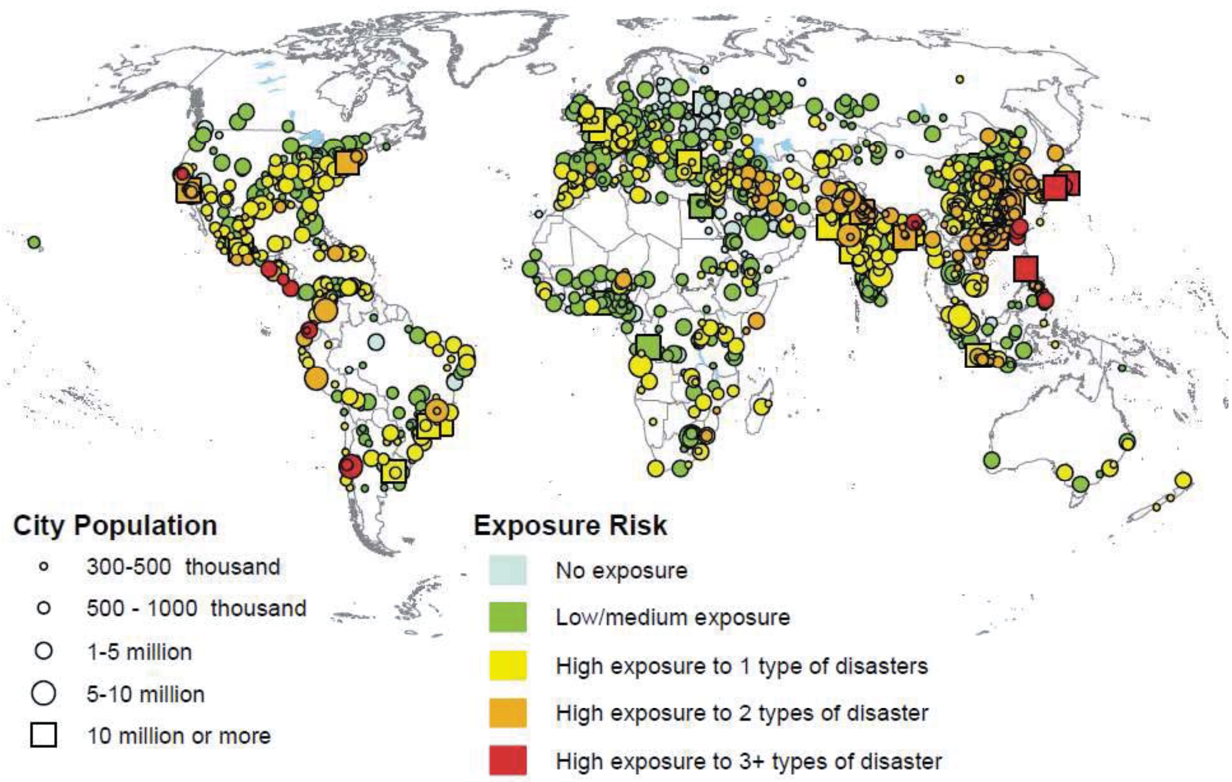


Image 1.6 *Rate of exposure to natural disasters of major cities worldwide. Almost all of the cities facing 3+ disasters are located around the Pacific Ocean, highlighting the role of geography in risk exposure. Source: UNDESA, World Urbanization Prospects: The 2014 Revision*

a marked increase in urbanization due to climate change factors alone. The reality is that these processes compound on one another, and the next century will without a doubt be one of constant growth for urban areas.

This has specific resonance geographically, since urban areas are not equally or randomly distributed across the map. Historically founded at points of connection (rivers, coasts, mountain passes), cities tend to concentrate on coastlines. This asymmetrical geographic distribution of urban centers means about 6% of the world's 7 billion inhabitants live within 5km of a coastline and almost 40% live within 100km, numbers that will only grow along with the population of the urban areas.[11] The concentration of population along coastlines presents a special concern from a risk and vulnerability standpoint: of the 15% of cities vulnerable to two or more natural hazards, most are located on a coastline (Image1.6).

The projected continued development in coastal areas increasingly puts both lives and economic capital at risk to the threat of natural hazards: over 80% of disasters reported by national sources occurred in urban areas[12]. Less developed nations, especially those in the hazard-centric zones such as the south pacific are especially at risk for loss of life, while increased construction and trade in more developed countries in the global north places ever more economic capital at risk: From the 1970's up to the mid 2000's, the proportion of the world's total GDP annually exposed to tropical cyclones rose from 3.6% to 4.3%, with the majority of that increase coming in developed nations.[13] This level of exposure is a direct result of the ways in which coastal areas have been developed over the past 200 years. Since at least the dawn of the industrial revolution coastal development paradigms worldwide have focused primarily on the consolidation of land for human exploitation, be that industrial, recreational, or housing.

The reality of our development paradigm comes into conflict with the other great worldwide process effecting cities in the 21st century: climate change. The evidence that the earth's climate is changing is widely accepted, and one need only look at the global shift in surface temperature of 1.1 degrees Celsius since the end of the 19th century, with 16 of the last 17 warmest years on record coming in the last 20, to understand why.[14]

The effects of this climate change have already begun to have repercussions in every city and country around the globe. Different altitudes, latitudes and localized topography can all influence the type and severity of effects of an increasingly

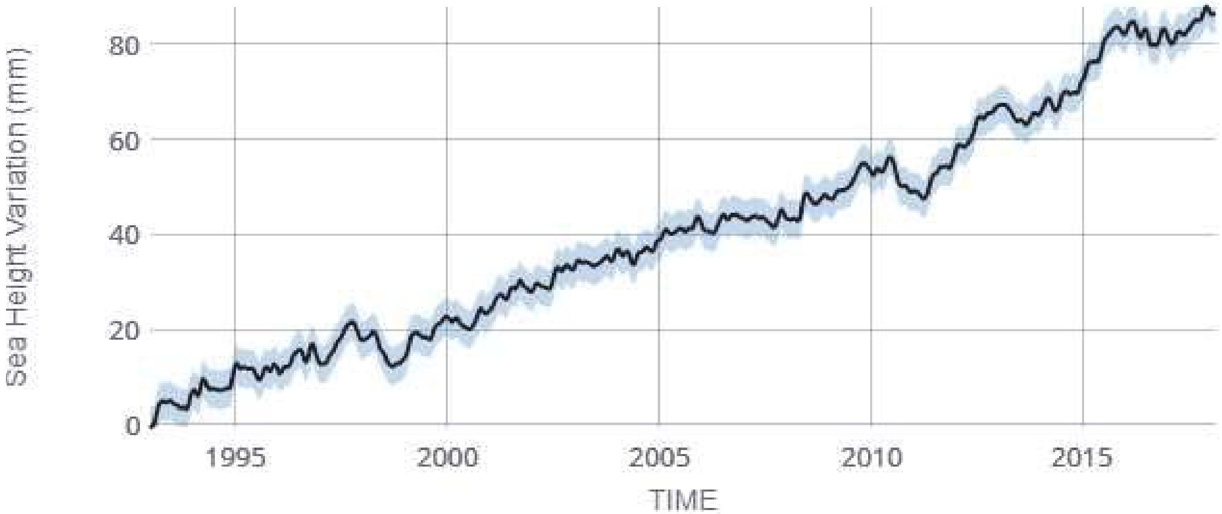


Image 1.6 *Global sea level height variation from 1993-2018. Overall rate of change is +3.2mm yearly. Source: https://sealevel.nasa.gov/understanding-sea-level/key-indicators/global-mean-sea-level*

warming world.

As shown in image 1.6, 2014 sea level had a global average 2.6 inches (67mm) higher than it was in 1993[15], and that average continues to rise at a rate of around 1/8 inch (3.2mm) per year. Sea levels are rising worldwide at an increased pace thanks to two repercussions of climate change: thermal expansion of the oceans and melting glaciers and ice caps. Thermal expansion is the process by which water expands as it gets warmer. As the planet warms, the oceans increase in temperature, causing their molecules to expand and the mean sea level across the planet slowly but inexorably rise. At the same time, the warming temperature on earth is causing land based ice like glaciers to melt as seen in image 1.7, releasing previously solid state water into the oceans, further raising the global sea level.

In order to tackle these two difficult challenges of the next century cities will need to draw on all sources possible. The concentration of peoples in cities exacerbates vulnerability, but it also offers unparalleled opportunity for innovation and creativity. Thanks to the interconnectedness of our world today, smaller, less developed cities have access to knowledge and experience from far beyond their borders with which to form their own responses. At the same time, larger, more developed cities with experiences in adaptation planning can offer a guide as to what form responses to climate change and extreme weather events can take.

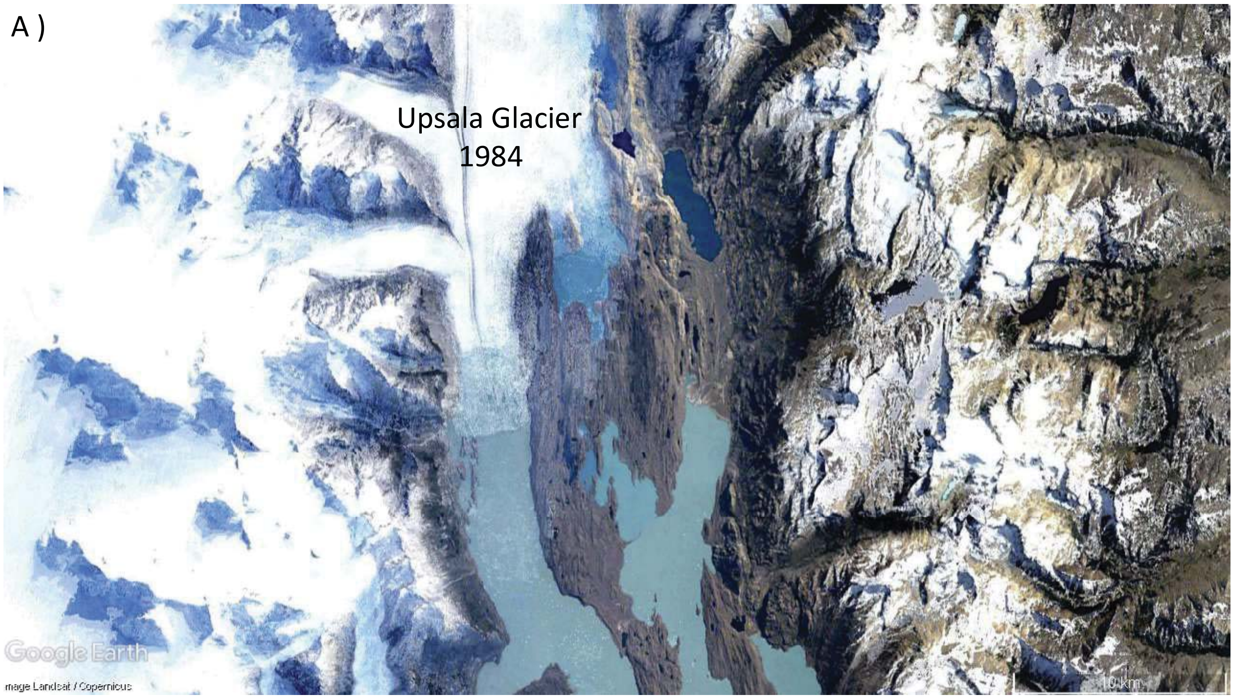
Using as a frame the development of coastal defenses along the ocean border of two cities on the Pacific edge of the American continent, this thesis seeks to advance the understanding of how the particularities and commonalities of cities effect the ways in which information and experiences in resilience adaptation can be translated between settings. This exchange will be crucial for cities in vulnerable areas like Valparaíso, Chile in particular as they attempt to adjust their current design and development paradigms with the reality of a changing world.

Vancouver and Valparaíso

All three typologies of border exploitation can be found at differing points along the coast of central Chile's Valparaíso Región between just the municipalities of Valparaíso and Viña del Mar (Image 1.8). The uses of the border in Gran Valparaíso speak with some specificity about the particular history of the area, but they also give an insight into development trends of coastal borders worldwide.

The development of the coast in all of Chile's fifth region, but especially Valparaíso and Viña del Mar, is heavily based around its relationship with the capital city of Santiago, just 115 kilometers to the southeast.

A)



B)

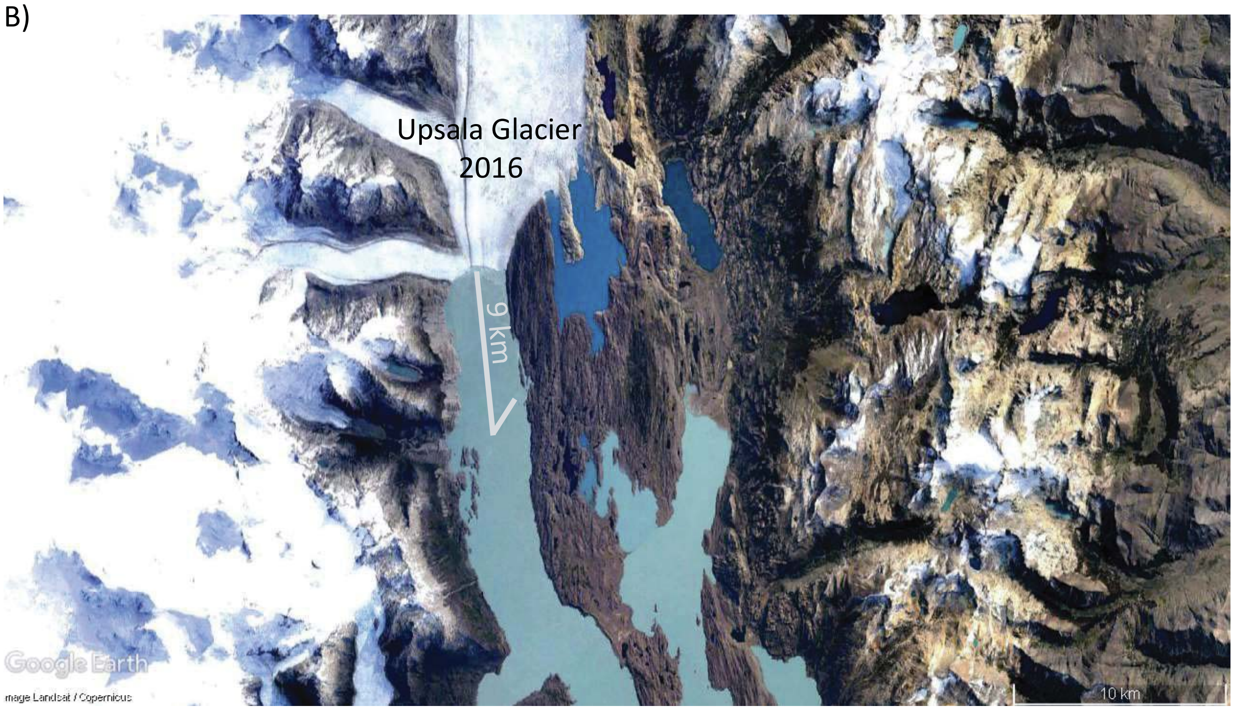


Image 1.7 *Evidence of glacial retreat, in this case of the Upsala glacier in Southern Chile. Picture A is from 1984, while picture B is from 2016. The distance retreated by the ice is equal to nearly 9 kilometers.*

Image 1.8 *Three typologies of coastal border development, from top: commercial at the port of Valparaíso. Stev Reise, [Photo] 2010, retrieved from http://spekuliereisen.com/blog/?page_id=565. Recreational at Caleta Portales. Playa Caleta Portales. [Photo]. Retrieved from https://playacaletaportales.wordpress.com/. Housing at Avenida Perú. Felipe Igualt [Photo] 2015. Used with permission from photographer.*

Image 1.9 *The proximity of Santiago played a major role in the development of the coastal border of Gran Valparaíso.*

Valparaíso's port, by virtue of its proximity to Santiago and convenient location for ships making the trip around Cape Horn, played a major role in focusing the development of its coastal border towards mercantilism. The process by which the coastal border of Valparaíso arrived to the industrial state is in today was not a passive process though. Despite how it may appear today, Valparaíso's border was not always as entirely relegated to port uses. Indeed, before the arrival of the rail connection between Santiago and Valparaíso in the mid 1800's, there were a number of recreational spots for Porteños of all class levels along the coastline. After the railway was completed, facilitating travel between the cities, the border began to change. The recreational areas (*baños*) were displaced towards the more well-to-do Viña del Mar as the railroad was given priority over the coastal region in Valparaíso, the industrial port city:

> *Beyond creating a symbolic and material limit with the sea, the extension of the rail line from Baron Station to the center of the center of the city was the catalyst for a series of instalations including warehouses, storage sheds, classification yards, housing for company workers and construction workers, all of which took coastal space and made it difficult to maintain the old recreation areas.* [16]

Today the border of Valparaíso remains dominated by the port and transportation needs, the only remnant of the old public access to recreation areas along the border are located on the outskirts of the city at *playa Las Torpederas* and playa *San Mateo*.

Even with the monopolization of the border in Valparaíso by the port and railway, it wasn't until decades later that Viña del Mar would capitalize on the opportunity and move towards a tourism based paradigm for their border. Even the tourist buildings that did exist were not oriented towards taking advantage of the coastline:the Gran Hotel, built in 1874 was over a kilometer from the ocean, and was touted more for its ease of connection to Valparaíso than for the city itself (Image 1.10). In the early 1900's though there was a recognition that with the proximity of Santiago and the lack of recreation areas in Valparaíso, an opportunity existed to create a new type of border in Viña del Mar, as shown by this 1922 letter in the local paper:

> *Let us create in Viña del Mar a modern beach town. It is inconceivable that nobody is interested in promoting tourism. An elegant beach town could act as a true a source of riches...Among the measures that the municipality should encourage would be: the foundation of modern bathing facilities, equipped with all the most appealing amenities; the foundation of a casino and a*

Image 1.10 1903 *advertisement for the Gran Hotel of Viña del Mar, no view of the coastline is shown, and the wording highlights the trains that run all day to Valparaíso. Carlos Torneo, 1903.*

> *thousand other activities that would make Viña del Mar an ideal site and attract tourists from every country.*[17]

In the following decades the planning paradigms guiding coastal use in Viña del Mar would shift towards specifically what the author called for, as the municipality positioned itself as a hub for visitors, building its casino in 1929, and offering an alternative but comfortable lifestyle for international tourists. As wealth in Chile grew and a middle class in Santiago formed in the mid 1900's, demand for second homes led to an expansion of property development in the coastline, which has continued into today:

> *The beach communities along the north-south axis of the Metropolitan Area of Valparaíso have shown high and persistent levels of investment and construction. In the last fifteen years it has been driven in residential areas as much by the secondary home projects for the richest 10% of Chilean households as for the development of urban highways for the macro central region...*[18]

In this paradigm of coastal development, which began in the 30's with the construction of the Municipal Casino, Avenida Perú, and Plaza Colombia, and persists today, the border became the façade for a reinvented tourist city.

Chile, as part of their national climate change plan (Plan de Acción Nacional de Cambio Climático 2017-2022), recognized the inherent possibilities in these relationships. One of the measures they promote as part of their goal of developing the capacity of local governments to respond to climate change is the exchange of information regarding successful experiences with other countries and localities (Ficha MG9: *Programa de Intercambio de experiencias exitosas entre municipios y gobiernos regionals y con pares de otros países, en materias de cambio climático*).[19] While possessing one of the most developed economies in Latin America, Chile is classified by the United Nations World Economic Situation and Prospects as a Developing Economy, and lags far behind other countries in terms of developing concrete plans for adaptation to climate change, especially considering the vulnerability of many of its most important areas.

As part of their national climate change plan and as defined by their agreement in the Paris Climate Accords of 2015, Chile has begun developing climate adaptation plans for individual cities. The second largest metropolitan area in Chile, and its most vulnerable to climate change, Gran Valparaíso, is in the course of developing their own plan, as recently as September of 2017 gathering community input into the process.

The city of Vancouver became one of the first

North American cities to address climate change with the 1990 report “The Clouds of Change”, and in 2012 the city dedicated itself to becoming the greenest city on earth in the Greenest City Action Plan. Vancouver has decades of experience planning for the same oceanic changes that currently threaten Valparaiso, and as a global city it commands a range of experience and a base of knowledge not locally available in the Zona Central of Chile.

Endnotes

1 UNDESA, World Urbanization Prospects: The 2014 Revision

2 Idem

3 UNDESA, World Urbanization Prospects: The 2014 Revision

4 UNDESA, World Urbanization Prospects: The 2014 Revision

5 UNDESA, World Urbanization Prospects: The 2014 Revision

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18 Guido Veliz. "Conurbación La Serena Coquimbo", Revista Geografica. Coquimbo, Chile 1990

19 División de Cambio Climático del Ministerio del Medio Ambiente, Gobierno de Chile. "Plan de Acción Nacional de Cambio Climático 2017-2022"

II-OBJECTIVES AND HYPOTHESIS

General Objectives

Explore the causes and effects of coastal flooding in cities on the west coast of the Americas and how responses to urban flooding events have incorporated the concepts of resilience in their infrastructure and urban fabrics.

Specific Objectives

-Develop a comparative study between two cities at differing stages of adaptation planning (Vancouver and Valparaiso) based on their geographic, demographic, and climatic profiles.

-Understand the potential current and future effects of coastal flooding in Vancouver and Valparaiso through case studies of historical extreme weather events in the two cities.

-Compare the local codes and adaptation plans geared towards mitigating or adapting to coastal flooding and extreme weather events.

-Evaluate what adaptation strategies may best be suited for Valparaiso to improve resilience at its coastal border.

Hypothesis

Coastal cities of the Americas will be heavily affected by the most destructive and impactful symptoms of climate change, and over the next 100 years, changes to storm surge levels produced by extreme weather events will require coastal cities to change the paradigms that guide the development and design of their coastal borders. Some cities, like Vancouver, have decades of climate change adaptation planning to draw on, while others, like Valparaiso are just beginning to incorporate climate planning into their future plans. Vancouver's experiences in climate adaptation can provide helpful examples for Valparaiso to follow as it begins the process of exploring coastal flooding mitigation options.

III-METHODOLOGY

This thesis is based on the following methodology:

1. Literature Review
    a. A review of the relevant literature and information surrounding resilience and adaptation. We specifically focus on the themes of resilience thinking and coastal adaptation strategies on which we will base our theoretical processes throughout the rest of the text.
2. Comparative Study
    a. While cities worldwide may share some similar characteristics and threats, each situation is fundamentally unique, and the optimal solution for one city may not be appropriate in another. Understanding the differences and similarities will be key to deciding which experiences can most appropriately and effectively translate from one area to another. Here we undertake an analysis of current and historic topographic, urban, demographic profile points in order develop a working comparison of the two urban areas.
3. Case Studies
    a. Proper evaluation of development paradigms requires us to have a firm grasp on the types of threats faced by each coastal area. For this we undertake a case study of past extreme weather events that have affected each coastline, developed from contemporary documentary analysis as well as post-event academic studies. This study aims not just to explore the relevant threats but also how each city has responded past events.
4. Adaptation Review
    a. Finally we explore the methods that Vancouver and Valparaíso have used in their approaches to adapting their borders to future coastal inundation. This exploration is done via review of local planning instruments, existing local adaptation/mitigation plans and an observational survey of current coastal defense solutions.

IV-LITERATURE REVIEW

Our theoretical analysis in this thesis is based on an urban systems framework that, first and foremost, conceptualizes the city as a *system*: a network of individual components defined by its function (its stable state) and its boundaries. The following section reviews relevant literature surrounding urban systems and how they display resilience, specifically to natural hazards.

Social Ecological Systems (SES)

Key to the concept of the social-ecological system is the understanding that systems can be dynamic and complex enough that more than one stable state may exist. Ecosystems with multiple equilibrium states and scales are fundamental to the concept of the Social-Ecological System (SES) and to our understanding of how urban systems display resilience. While the academic notion of the Social-Ecological System is an evolving field, a review of the literature surrounding the concept suggests that an SES is defined by the following four criteria:

- An integrated system that spans across matter, life, and human social and cultural phenomena.
- A system consisting of relationships between elements at multiple scales and within nested systems.
- A system which is complex and adaptive, with properties of self-organization and emergence.
- A system with abstract thought and symbolic construction.[1]

The SES framework, and particularly how it applies to cities, is the context within which we will be examining resilience. The city is not simply a collection of built and green spaces; of people and animals; of pathways and edges; of landmarks and connectors. Rather it is all of those things at once and more. Modern cities are incredible amalgamations of human beings, nature, and the built environment, combining on

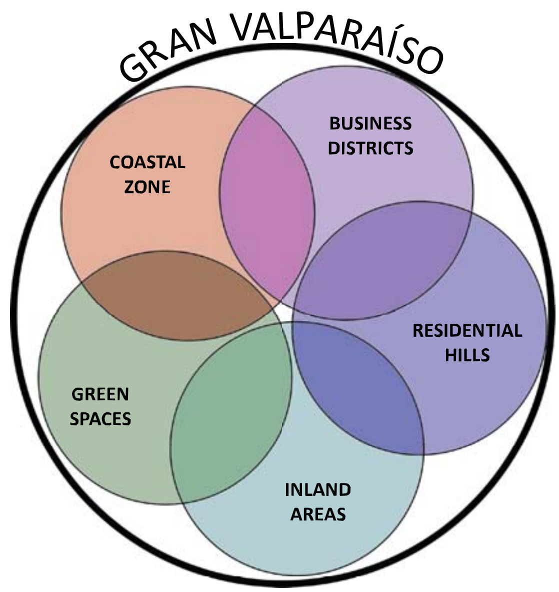


Image 4.1 *The city as a Social Ecological system comprised of individual systems nested together, acting on mulitple scales.*

multiple scales into exceedingly complex systems. Together, those individual systems form together to create a City; a large Social-Ecological System with its own characteristics and dynamics. Understanding the coastal border as a contained system in itself, while simultaneously being part of a larger system,

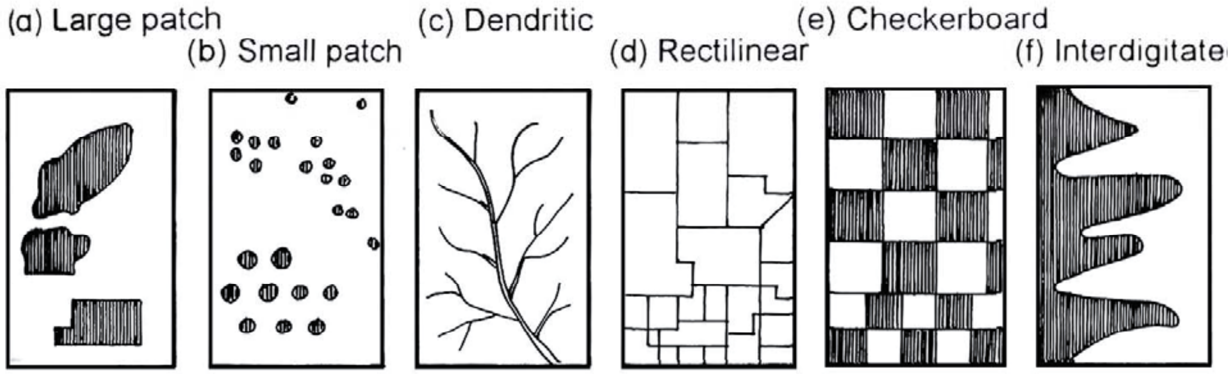


Image 4.2 *Landscape Ecology conceptualizes the landscape as an interconnected series of patches, or mosaics, that have diverse and complex relationships between each other. These examples of mosaics are based off Richard T.T. Forman's 1995 book* Land Mosaics: The ecology of landscapes and regions. *Amanda Bayley. [Image] 2008. Retrieved from http://portfolio.amandabayley.com/landscape-architecture/*

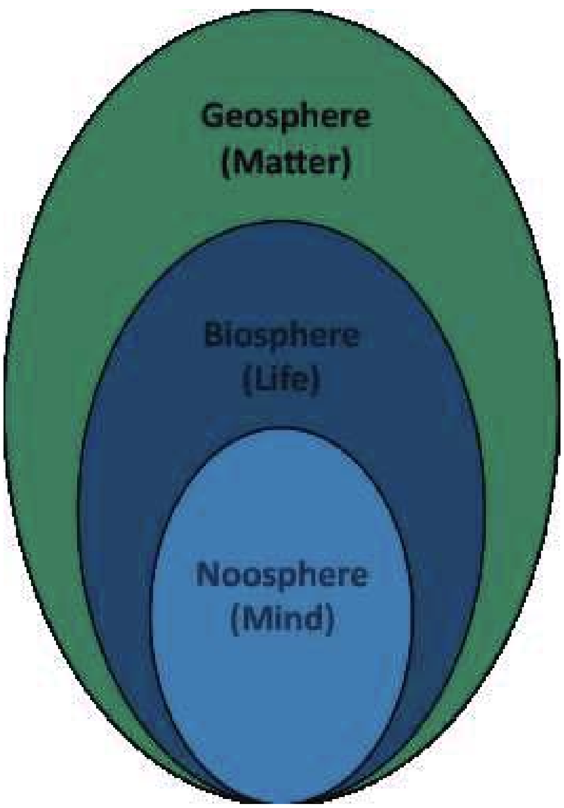


Image 4.3 *The three spheres of existence of a social ecological system. Adapted from Du Plessis, 2008.*

will be key to our concept of resilience moving forward (Image 4.1).

The concept of the city as an ecological system is not a new one, dating back to at least the mid 1900's with the development of landscape ecology and its focus on interactions between mosaics of interconnected patches of land (Image 4.2).[2] However, more recent studies have moved beyond simply applying an ecological framework to the analysis of human settlements towards an attempt to interpret the city as a complex ecological system with uniquely social aspects that affect its function.

This framework is useful for emphasizing the unique role that human value systems play in the dynamics of city SES, driving choices on multiple scales that can ultimately affect the citywide biophysical system. Indeed, Plessis' synthesis suggests that the SES of the city is composed of three interlocking spheres of existence (Image 4.3): the geosphere (matter), the biosphere (life), and the noosphere (mind).[3] The three spheres are a nested continuum, as life requires and is born from matter, and mind requires and is born from life. It also highlights the SES as a *panarchy*, namely, a structure in which the individual systems have relationships across scales and hierarchies[4]. This interweaving of scales means that actions taken in the smallest of subsystems can ripple across other component systems and affect the SES as a whole.

Resilience

The etymology of the word resilience can be traced back to the latin word *resilere*, meaning "to rebound" or "to recoil".[5] In some disciplines, the modern day usage of the word doesn't stray far from those roots, such as in engineering, where resilience refers to the ability of a material to absorb energy when deformed elastically and the recovery of that energy when returning to its original state.[6] In its psychiatric and psychological connotations resilience also hews close to its original Latin connotation, as it represents to the ability of individuals to process life changes and transitions.[7] On a much larger scale is the similar concept of societal resilience: *the ability of groups or communities to cope with external stresses or disturbances as a result of social, political, and environmental change*.[8]

It was the usage of the word in the field of ecology however, that precipitated the proliferation of resilience studies across the many fields that it reaches today. C.S. Holling introduced the concept of resilience in ecology in his 1973 article *Resilience and the Stability of Ecological Systems*, where he described it as the "*measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables*."[9] Holling and his collaborators continued to iterate on the definition of resilience, and in a 1996 paper he explicitly differentiates between his definition of ecological resilience, and that of what he terms 'engineering resilience'. Engineering resilience, he explains, measures the resistance to disturbance and the speed of return to equilibrium, while ecological resilience measures the amount of disturbance that a system can undergo before fundamentally changing its character:

> *One definition focuses on efficiency, constancy, and predictability-all attributes at the core of engineers' desires for fail safe design. The other focuses on persistence, change, and unpredictability-all attributes embraced and celebrated by biologists with an evolutionary perspective and by those who search for safe fail designs.* [10]

Image 4.4 *US fire management policy has generally been arranged around suppressing forest fires whenever possible, increasing short term resilience to hazards, but that has allowed underbrush and grasses to flourish, creating environments primed for massive mega-fires like we have seen in Califronia over the past several years. Bob Strong, Rueters.[Photo] Retrieved from http://news.abs-cbn.com/overseas/07/30/18/come-and-get-me-boy-pleaded-before-california-fire-death*

The relationship between these two types of resilience may not necessarily be aligned, meaning that designing a system to increase short term engineering resilience may in fact reduce long term ecological resilience.[11] Holling illustrates this point with examples from ecological systems that sacrificed long term stability for short term efficiency, such as in the managed forest ecologies of the western United States (Image 4.4), but examples exist in other contexts as well. Designing to increase resilience to one hazard, such as using wood framing in housing to resist frequent seismic activity, can detract from another, such as when a fire spreads rapidly through tightly packed wooden buildings.

What these various definitions of resilience ultimately display is that context matters, and that our definition of resilience, and resilience thinking, is influenced by the setting in which we are evaluating them. For our purposes we will be working with the definition of resilience provided by Walker, et al. in 2006 in regards to Social Ecological Systems: "*the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks*".[12] There are four aspects that define the resilience of any system, and while the first three apply across any scale, the fourth applies specifically to integrated systems (SES) as a whole.

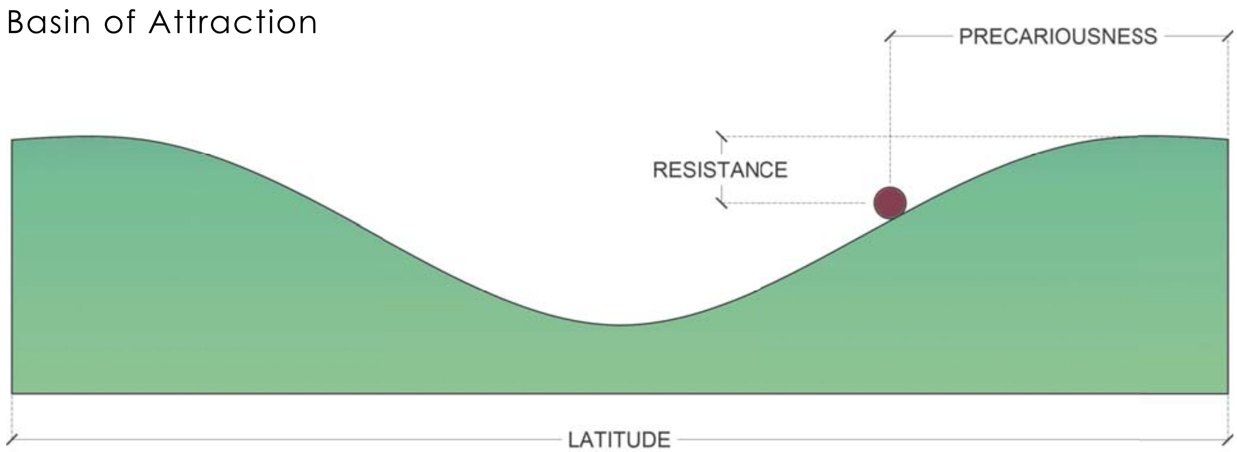


Image 4.5 *How an individual system functions within its Basin of Attraction, and the aspects that define its resilience. Adapted from Walker, et al. 2004.*

-Latitude: corresponds to the maximum amount a system can change before it crosses a threshold beyond which recovery is difficult or impossible.

-Resistance: the ease or difficulty of changing the system

-Precariousness: how close to the threshold the current state of the system is

-Panarchy: the influence of other subsystems on the resilience of the given system[13]

These four aspects operate within what can be termed a 'basin of attraction'[14] (Image 4.5), a theoretical region within which the system remains stable and functional, responding normally to individual subsystems of which it is formed. In real world SESs, a system tends to move within this basin of attraction, pulled to its equilibrium state but constantly beset by random disturbances (like natural hazards) and decisions from human actors that move it away from equilibrium.

Regardless the field of study, resilience in hazard management tends to revolve around four key actions: *preparation*, *resistance*, *recuperation*, and *adaptation*.[15] Preparation is the stable state that a system rests at between disturbances, and the ways in which it organizes itself for the next event. Resistance, as noted before, is the system's ability to withstand change and maintain functionality. Recuperation is the way the system returns itself to its pre-disturbance functionality. Adaptation is the system's capacity to rearrange itself to better confront future disturbances.[16] These four actions can be conceptually arranged in a circle, called the cycle of resilience (Image 4.6) that help illustrate the cyclical nature of hazards and responses.

An important distinction is between simply mitigating risk and the more complex task of building resilience. Rosati, et al explain the drawback to attempting to design specifically for reducing risk:

> *A risk management approach addresses the vulnerabilities of specific systems and quantifies the loss of functionality of that system in the event of specified hazardous event(s). Once functionality of the system is understood, solutions can be offered to better prepare the system to prepare and resist the hazard. As the dominant assessment strategy for engineered systems risk management aims to offer solution in anticipation of known hazards with the expectation that operations will continue as normal… However, complex systems often pose problems for the risk manage management approach because feedback loops, interdependencies, future unknown and variable spatial and temporal scales can result in hazards and community settings that are varied and unpredictable.*[17]

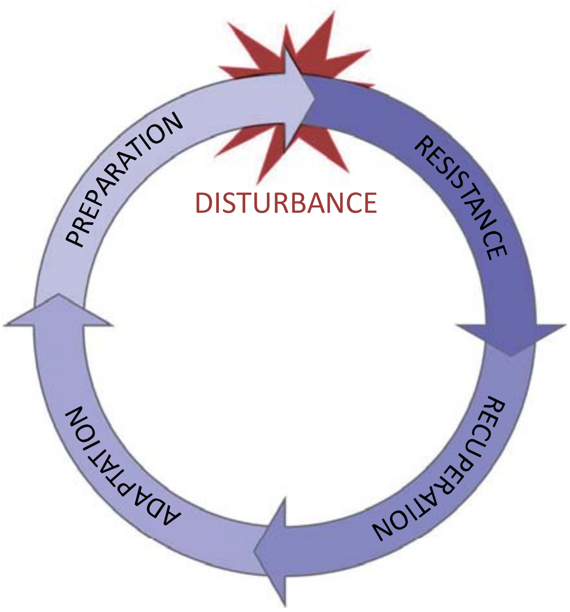


Image 4.6 *The 'cycle of resilience'. Adapted from Rosati, et al. 2015.*

Whereas improving the resilience of a system based around the idea that future unknown variables, be they ecological, biological, or physiological, will undoubtedly arise to adversely affect the stability of the system. Preparing for the unpredictable means incorporating the ability to change and adapt to multiple disturbances across the panarchy of systems.[18]

Resilience Thinking

In discussing how Vancouver and Valparaiso have approached threats posed by natural hazards and sea level rise we will be employing a concept called resilience thinking. A term coined in *Resilience Thinking: Integrating Resilience, Adaptability and Transformability*, resilience thinking is an approach to analyzing social-ecological systems that recognizes the capacity of a system to adapt and transform as vital to its persistence.[19] In terms of cities, it means adapting to an urban design paradigm that encourages planners and designers to embrace the possibilities inherent in both sudden and gradual changes, and rests on two main concepts: adaptability and transformability.

Adaptability and Transformability

Adaptability, in the context of a social ecological system, is understood specifically as the ability of the human actors within a system to influence the aspects of resilience mentioned above. This is an explicit recognition that the ecological outcomes in an SES are primarily dictated by human actions taken in integrated systems.[20] The human element introduces variance into an SES unseen in strictly ecological systems in the form of human values and norms that not only help shape the built environment, but also the response to disturbances that affect it. Individuals, organizations, institutions, and evens societies can 'learn' from past events and arrange themselves to better respond to events. This is fundamental to the difference between ecological and social-ecological systems: disturbances to the system are not simply shocks, but opportunities to learn and reorganize according to past experiences. It's this faculty for abstract thought and symbolic construction that serve as the key to resilience thinking: there are opportunities of growth and reorganization not present in ecological systems that lack the agency to alter their trajectories.[21] Agency works both ways however, as Berkes notes:

> *Since human actions dominate social-ecological systems, adaptability is mainly a function of the social component of the integrated system. However, adaptation is not a mechanistic or predetermined outcome. Human agency including the role of individuals, leaders and institutions, is important and influences outcomes. This collective capacity to manage resilience determines whether thresholds can be successfully avoided.*[22]

Unlike strictly ecological systems, which overtime will naturally adapt themselves to their environment, an SES places the onus of adaptation onto the human actors involved. If they choose not to engage in the process, or have a negative overall influence, the system's adaptability suffers greatly.

Avoiding thresholds is generally the goal of building a resilient system, but occasionally it may become necessary for the system to change the variables around which it is arranged. This action is called a transformation, and the ease with which it occurs is called transformability. In resilience terms, this is what occurs when a system absorbs change greater than its latitude, and crosses a threshold into another basin of attraction, arranging itself around new equilibrium states.[23] While this is generally the outcome to be avoided in a systems framework, Resilience Thinking suggests, somewhat paradoxically, that the transformation of an individual system may

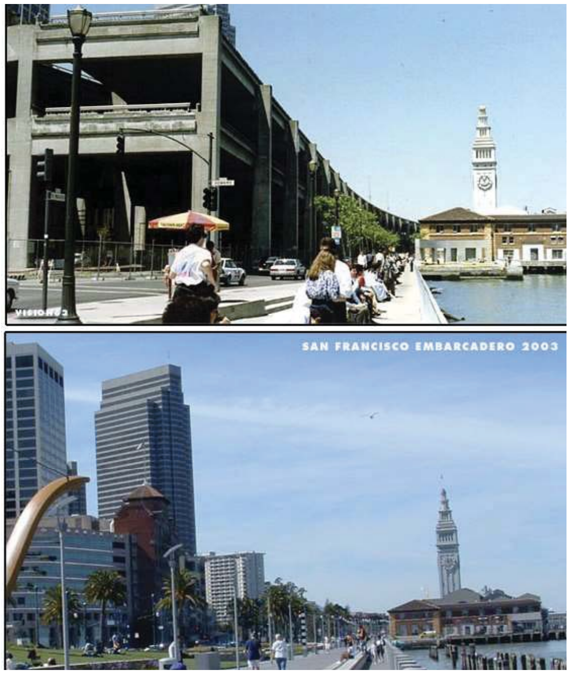


Image 4.7 *The San Francisco waterfront at Embarcadero in 1992 (above) and 2003 (below), before and after the removal of the Embarcadero freeway. San Francisco Planning Department. [Photo] 2015.Retrieved from http://www.upout.com/blog/san-francisco-3/old-san-francisco-a-look-at-before-and-after-the-embarcadero-freeway-came-down*

be necessary for the long term resilience of connected systems to which it is related across the panarchy. Chelleri tell us that:

> *Because of such (short term) recovery perspective of resilience some important (long term) sustainability goals are missed or misunderstood. In fact simply trying to make systems more robust to changes may lead unsustainable systems to resist over time. As in the Schumpeter economic concept of creative destruction (Shumpeter, 1942) long term resilience requires constant transformations across different scales, components (groups), or subsystem collapses in order to make the entire system evolve*.[24]

This perspective suggests that in order for large scale complex systems, like a city, to survive over time, it may be necessary for its component systems to occasionally fail, or transform. An example of this action can be found in the way in which the San Francisco waterfront transformed itself after the Loma Prieta earthquake in 1989 damaged the existing freeway there. Instead of investing in the repairs that would be necessary, the city removed the freeway entirely, and converted the area into an open boulevard with ample green space and access to the waterfront (Image 4.7).

Mitigation and Adaptation Plans

In recognition of the costs, both in terms of lives and dollars, that natural disasters pose, and their accompanying increase in potency and frequency thanks to climate change, local and state governments have taken it upon themselves to develop hazard mitigation and adaptation plans that seek to address the threats they face. Hazard mitigation plans (HMP) and Adaptation Plans (AP) both seek in their own way to defray the eventual costs associated with the intersection of human settlements and nature, though their focuses and strategies differ.

Hazard Mitigation Plans focus on reducing "the loss of life and property, human suffering, economic disruption, and disaster assistance costs resulting from natural disasters."[25] Specifically, HMPs identify the hazards and threats most likely to affect the indicated area, and subsequently present the most implementable strategies to mitigate them.

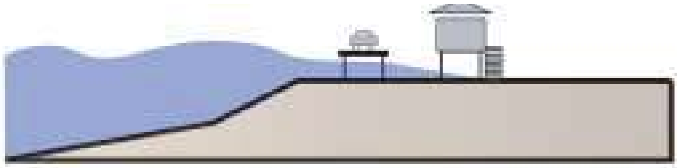
Adaption Plans generally build on top of Hazard Mitigation Plans, identifying what aspects of the HMP will be affected by future climate change, and presenting options to reduce both the effects on by those hazards, but also the city's overall contribution to global climate change.

While it is possible to have one type of plan without the other, a comprehensive study of 200 cities in Europe shows that in practice, the two are closely linked. They found that not a single city studied had an adaptation plan without previously detailing a Hazard Mitigation Plan. The study also showed that while it may be true more and more localities are willing to invest in planning for hazards and climate change, they are far from ubiquitous: 35% of the cities examined had no mitigation plan, and a full 72% had no adaptation plan.[26]

Despite this finding, both plans are becoming more common worldwide, and they are mainly found in developed nations, the UN, recognizing the disproportionate danger posed by climate change to developing nations, has made a concerted effort to encourage less developed nations to consider mitigation and adaptation options. These efforts include the National Adaptation Programs of Action established by the United Nations Framework Convention on Climate Change (UNFCCC) in 2001, which allows for least developed countries to apply for grant money that allows them to undertake urgent adaptations to increase resilience to hazards associated with climate change. Other events, like the World Conference on Disaster Risk Reduction, held every ten years in Japan since 1995, work to raise the profile of hazard mitigation efforts worldwide. Of particular note is the Hyogo Framework for Action, adopted at the WCDRR in Kobe in 2005. Held just a month after the Indian Ocean tsunami that killed over 200,000 people, the backdrop of such a disaster brought the issue to the forefront as governments worldwide were encouraged and incentivized to prioritize minimizing disaster risk in their countries.[27]

Coastal Adaptation Strategies

Strategies undertaken with the aim of increasing resilience in the coastal region of urban areas fall into three broad categories, *adapt*, *protect* and *retreat*, which are explored in the following image (Image 4.8):

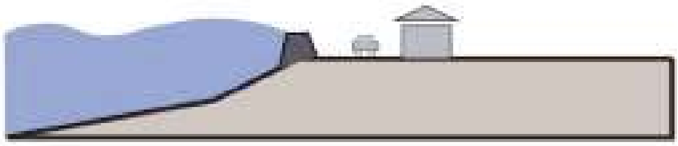


ADAPT

Adapt strategies focus on reducing exposure or vulnerability of assets during a flood event. Often called 'soft' defenses, these strategies are based around changing or tweaking existing infrastructure or behaviors. Examples of strategies that adapt their target include:

-zoning laws that change the urban fabric of an area by permitting only certain typologies of buildings in certain areas or construction laws that specify the use of flood resistant materials or methods

-forecast and warning systems that advise residents of potential flood events

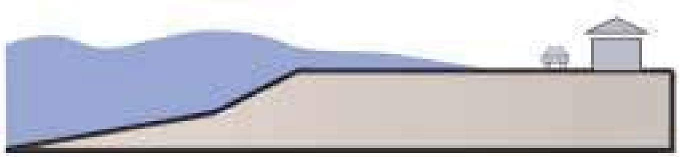


PROTECT

Strategies for protecting assets reduce risk by preventing or mitigating the negative effects of the inundation, protection strategies, also called hard defenses, can include:

-sea or inland dikes

-sea walls or wave breaks



RETREAT

Retreat, probably the most extreme of the adaptation strategies, involves actively moving vulnerable assets out of the hazard area. This can be achieved by:

-proactively forcing homes and residences away from the coastline or danger area

-reactively choosing to not rebuild in a certain area after a disaster

-gradually over time buying out private property and rezoning the area

Image 4.8 *The three adaptation strategies employed in coastal defenses: Adapt, Protect and Retreat.*

(Endnotes)

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18 Seager J. Park “Integrating risk and resilience approaches into catastrophe management in engineering systems.” (Risk Anal 33(3):356–368. 2013)

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24 Chelleri, 2012

25 FEMA Local Mitigation Handbook

26 D. Reckien, et al. “Climate change response in Europe: what’s the reality? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries” (Climatic Change, 122, issue 1, p. 331-340)

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V- CONTEXTUAL STUDIES

As noted previously, the two urban areas explored in this paper are that of Vancouver, British Columbia, Canada, located in the Cascadia Region of North America (Image 5.1) and that of Greater Valparaiso, located in the Central Zone (*Zona Central*) of Chile in South America (Image 5.2). Both are important maritime cities to their respective regions with deep ties to the Pacific Ocean on which they rest. We will be focusing specifically on the most important municipalities in each urban area: the City of Vancouver in Metro Vancouver, and the municipalities of Valparaíso and Viña del Mar in the conurbation of Gran Valparaíso. The following section is an attempt to place each urban area in its geographic, climatic, and demographic context.

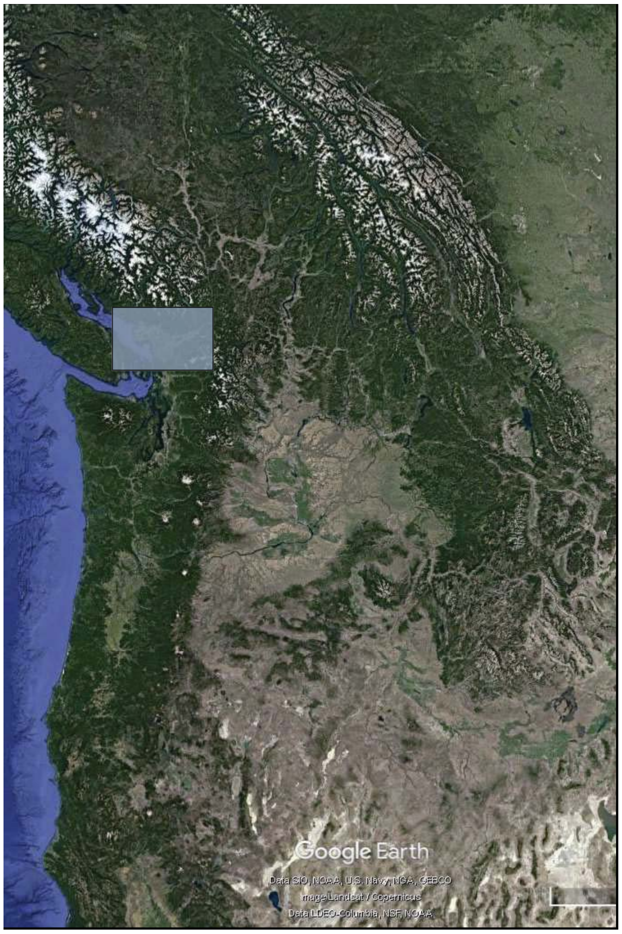
Geographic

Over millions of years, the earth's tectonic forces have formed both Cascadia Region of North America (Vancouver) and the *Zona Central* of Chile (Valparaiso) in very similar ways. Comprehending their similarities, and how they relate to the challenges each city faces regarding extreme weather events and climate change requires us to understand the underlying forces at work in the shaping of the planet.

Both the Cascadia Region and the Zona Central are defined by two major topographic landmarks: their coastline with the Pacific Ocean and their respective coastal mountain ranges. Those mountain ranges, the Cascade Mountains in the Cascadia Region and the Andes Mountains in the Zona Central provide a frame which defines the climate, landscape, and to a large extent, the culture of the regions. While imposing spectacles in their own right, both ranges are in truth part of a much larger mountain range: the American Cordillera, which runs the entire length of the American continent in one form or another, from the southernmost parts of Chile through western Canada (Image 5.3). Understanding how this mountain range has shaped the past and present of both Cascadia and the Zona Central of Chile requires an understanding of the way the great plates which constitute our earth work.

The science of tectonic plates is accepted as the standard model to understand the structure and working of the planet earth. According to this model, the world is composed of spherical layers that surround a nucleus of superheated iron. From the interior to the exterior the layers are: the inner core, the outer core, the mantle, and the crust. For our exploration of the geology and topography of the Americas, we will concentrate on the mantle and the crust.

The mantle is composed of three layers of iron and magnesium silicate of varying consistencies. Immediately after the core the mantle is solid, though sufficiently plastic to flow slowly. After the mantle,



Metropolitan Vancouver

-Located in Pacific Northwest of North America (Cascadia Region)
-Largest city in Western Canada
-Home to 2.5 million residents over 3000 square kilometers

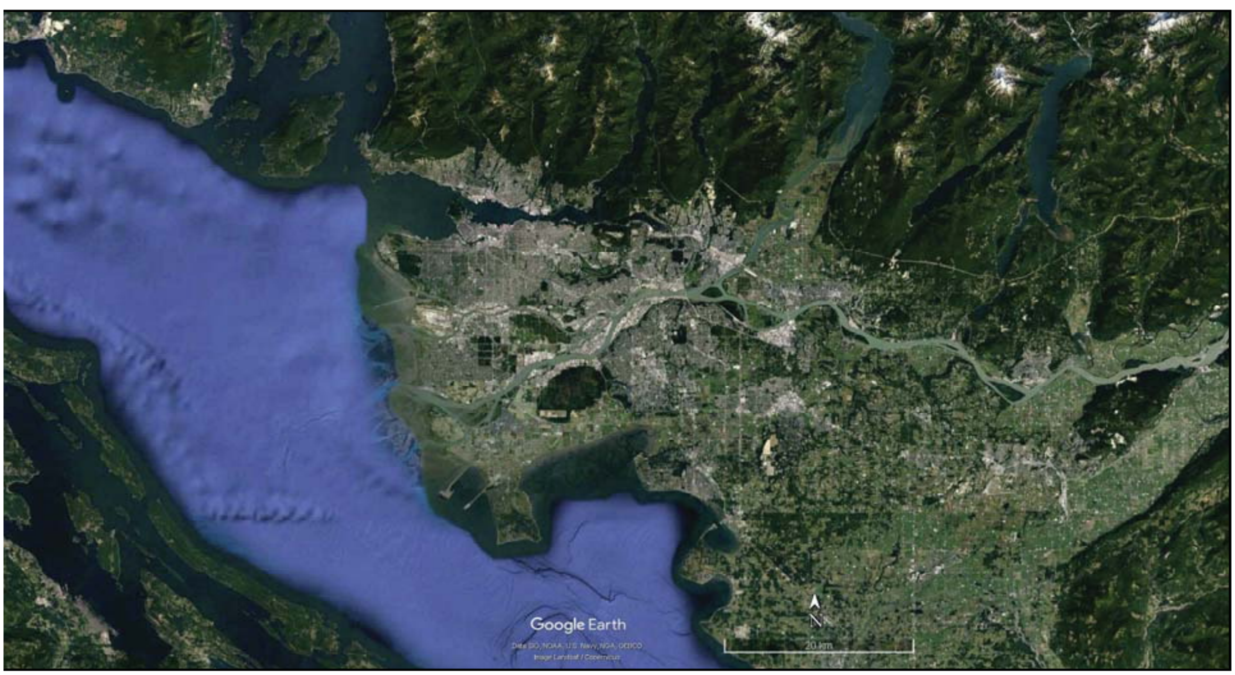
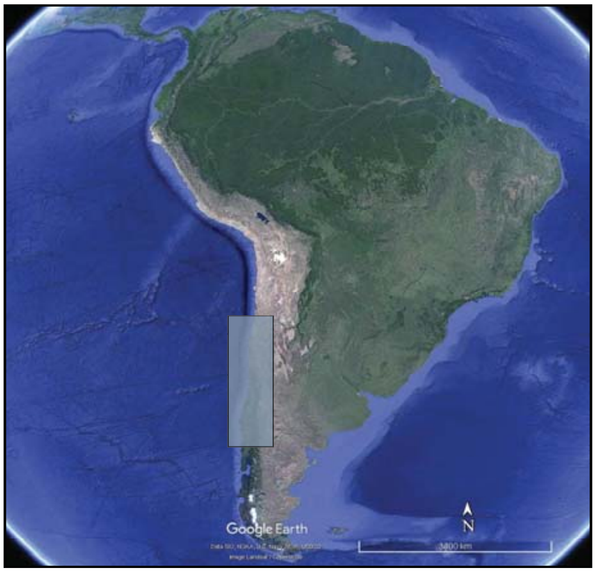
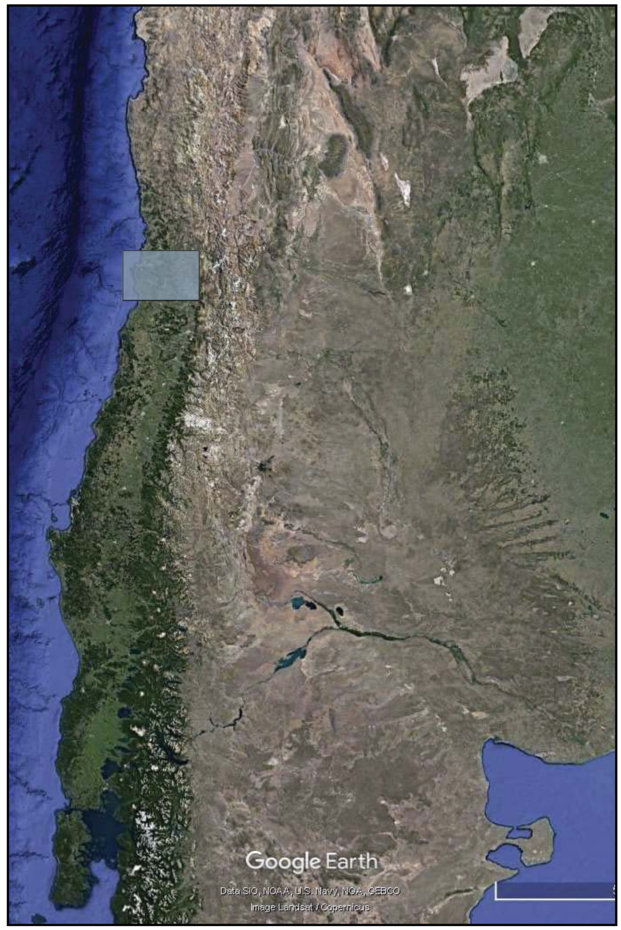


Image 5.1 *Location of Metropolitan Vancouver in the Pacific Northwest of North American continent. Source for all images Google Earth.*





Gran Valparaíso

-Located in Zona Central of Chile (Región V - Valparaíso)
-2nd largest conurbation in Chile after capital of Santiago.
-Home to 1.2 million people over 700 square kilometers

Image 5.2 *Location of Gran Valparaíso conurbation on the South American continent. Source for all images Google Earth*

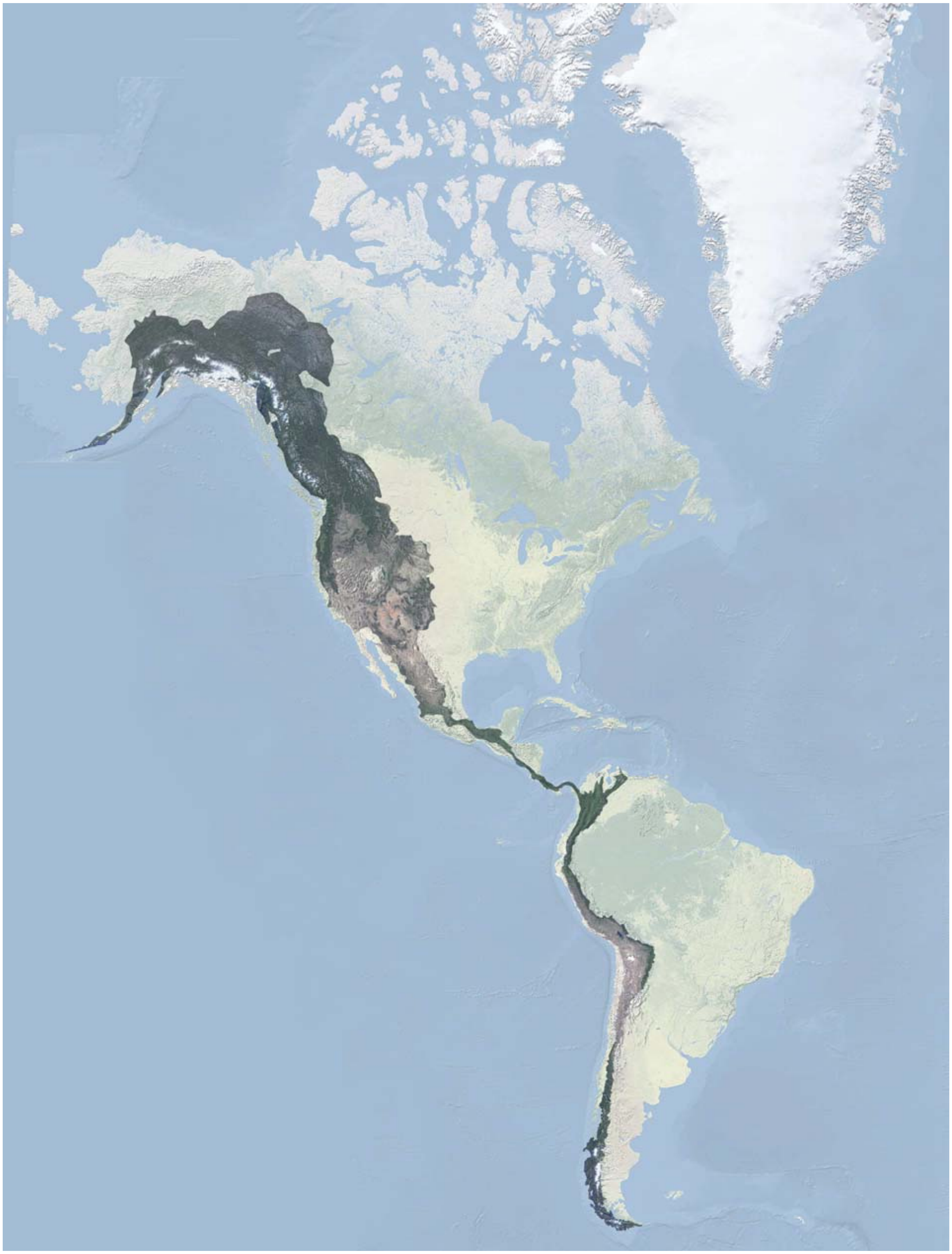


Image 5.3 *The American Cordillera, formed by similar tectonic forces runs the length of the Americas and defines much of the local climate and culture.*

there is a layer of liquid magma, called the asthenosphere, and finally a layer of rigid rock. The crust, like the outer layer of the mantle, is rigid and composed primarily of granite under the continents, and basalt under the oceans. Together, the two rigid layers of the mantle and crust are called the lithosphere, and exist not as a continuous layer but as a series of independent plates. In the relevant literature, plates are generally categorized by size, with between 8 and 14 'major' plates, though the definition of 'major' can vary from author to author. Despite the variation, always included within the range of the major plates are those with the most consequence to the geology and topography of the west coast of the Americas: in North America, the North American Plate; in south America, the South American Plate; and to the west of both of them, the Pacific Plate (Image 5.4). In addition to these three main plates there are two more that play a critical role in history of the Zona Central of Chile and the Cascadia Region. Sometimes counted as major plates, other times as secondary plates, the Juan de Fuca plate in the northern hemisphere and the Nazca plate in the southern hemisphere both interact with the plates around them to create the topography we see today.

As two plates moving towards each other meet, one is inexorably forced beneath the other, creating pressure both in the zone where one plate is diving beneath the other,

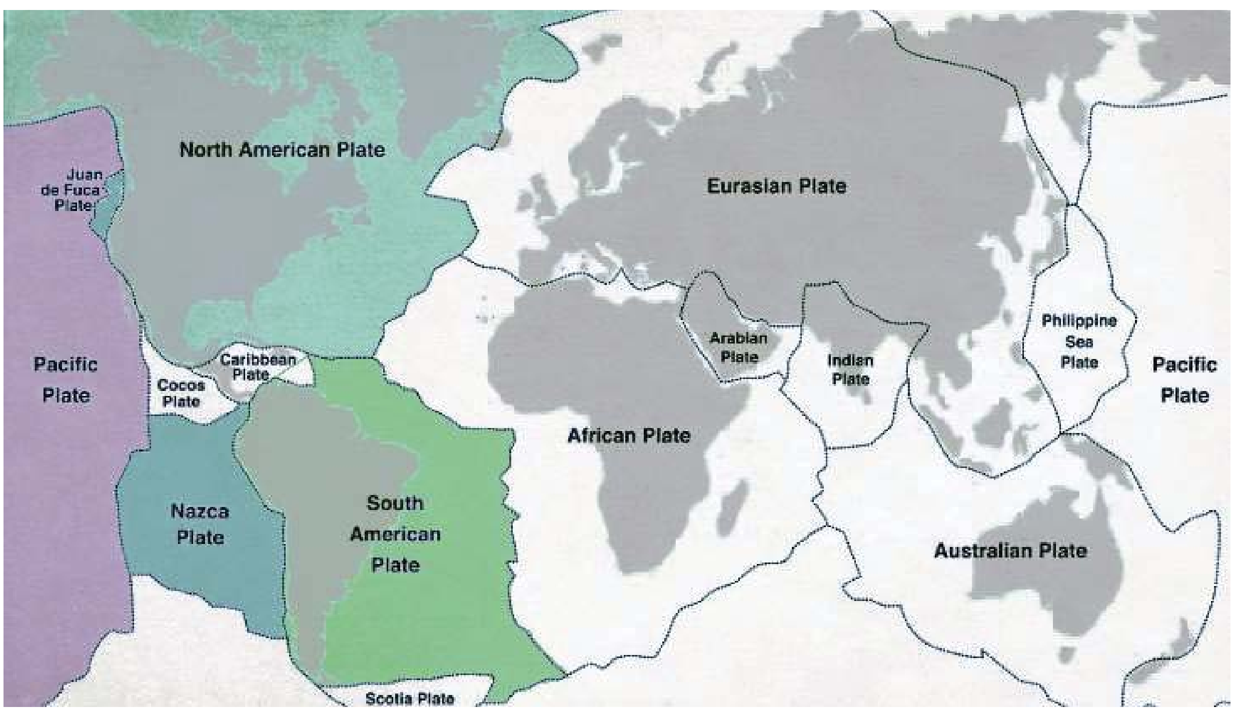


Image 5.4 *Map of the major tectonic plates worldwide, with the plates most important to the formation of the west coast of the Americas highlighted. Adapted from worldatlas.com*

but also in the separate plates themselves. Oceanic plates, composed primarily of basalt, are denser than their continental counterparts, thus when an oceanic plate meets a continental plate it moves under the lighter plate, pushing up sediment from the continental plate in a wedge to form mountains along the coastline, a process known as orogeny. Internal thrusting on the continental plate eventually allows magma to rise up from the asthenosphere through the crust and volcanic hotspots are created in those same mountains, as seen in image 5.4. This is the situation that produced the entire American Cordillera, as the North American and South American tectonic

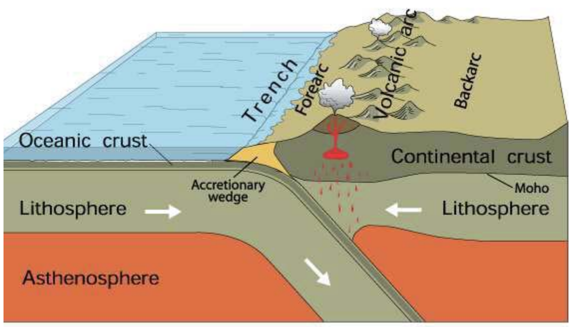


Image 5.5 *This image from the United States Geological Service shows the forces at work in a subduction fault zone between a continental plate and an ocean plate. Source: USGS, https://www.usgs.gov/media/images/subduction-fault-zone-diagram*

plates respectively subucted smaller oceanic plates along their borders and through the slow process of orogeny, gave rise to coastal mountains.[1]

The result is a remarkably similar topography along the entire western coast of the Americas, what Inman and Nordstrom (1971) classify as *collision-edge mountainous* coasts[2]: coastlines that both lie along the collision edge of tectonic plates and have mountainous terrain with a short continental shelf. Both Chile and Cascadia meet this criteria, as Chile averages just 175km between the coastline and the Andes, which also serve as the border with Argentina; in Cascadia, the cascade mountain range sits between 160-240km from the Pacific Ocean depending on the latitude. Both mountain ranges rise well over 3000m and contain a mix of active and extinct volcanoes. And in both coastlines, the stretch of continental plate that lies under water, also known as the continental shelf, is quite narrow (under 50km wide). One major and impactful difference in their morphology is the presence of barrier islands in Cascadia. While the Central Coast of Chile lies completely exposed to the Pacific Ocean, as we see in image 5.1, most of the major population areas of Cascadia are shielded from direct contact to the ocean by a series of islands, including Vancouver Island, the largest island on the west coast of the Americas.

Metropolitan Vancouver Geographic Setting

Although the Cascadia Region of the North American continent, also known as the Pacific Northwest (PNW), does not have a legal designation in either Canada or the United States of America, its geographic boundaries are generally understood to include the states of Oregon, Idaho and Washington of the United States of America, and the southern part of the Canadian province of British Columbia. In terms of population, Cascadia is moderately large: it lacks a megacity like Los Angeles, Chicago or New York, but it does have three metropolitan areas (Portland, Oregon; Seattle, Washington; Vancouver, British Columbia) each of which is home to at least 2 million people.

The Vancouver Metropolitan area is located at latitude 49˚, longitude 123˚ in British Columbia, the westernmost of Canada's thirteen provinces and territories. The largest city in western Canada, it sits just across the border from the United States, around 180km from the US city of Seattle.

Thanks to its location east of Vancouver Island, the city of Vancouver is reasonably sheltered from the major storms that pass through the area. Despite its relative security behind the buffer of the largest island on the west coast of North America though, the city remains permanently in danger of storm related flooding and damage because of the sheer number of bodies of water by which it is surrounded. To the north is the Burrard Inlet, to the west the Strait of Georgia, and to the south is the Fraser River. The numerous streams that

Image 5.6 *The city of Vancouver is the largest municipality in the area of Metro Vancouver*.

once ran through the city have almost all been paved over, replaced by an extensive storm sewer infrastructure, which can back up when sea levels rise too high, as during extreme high tides.

Gran Valparaiso Geographic Setting

Although there are small cities and towns up and down the central coast of Chile, the only large urbanized zone is the conurbation of Gran Valparaiso, located in Chile's V region on the Pacific Coast at latitude 33˚ south and longitude 71˚ west, about 115 kilometers northwest from the capital city of Santiago.

Although the total area of Gran Valparaiso stretches inwards towards the coastal mountain range, the heart of the conurbation sits on the coast in the hills and flatlands that surround the Bay of Valparaiso. Three municipalities border the bay, Valparaíso, Viña del Mar, and Concón, while Quilpué and Villa Alemana are located inland. Viña del Mar and Valparaíso, the two most developed and populous of the municipalities, are the focus of this investigation. The development of the urban area, in the past and today, is tied strongly to the port located at the foot of the sloping hills of the municipality of Valparaiso. From its initial settlement in the 16th century, the port of Valparaiso quickly developed into the most important anchorage in Chile, and one of the major stops in the worldwide shipping trade that dominated the 19th century. Its meteoric

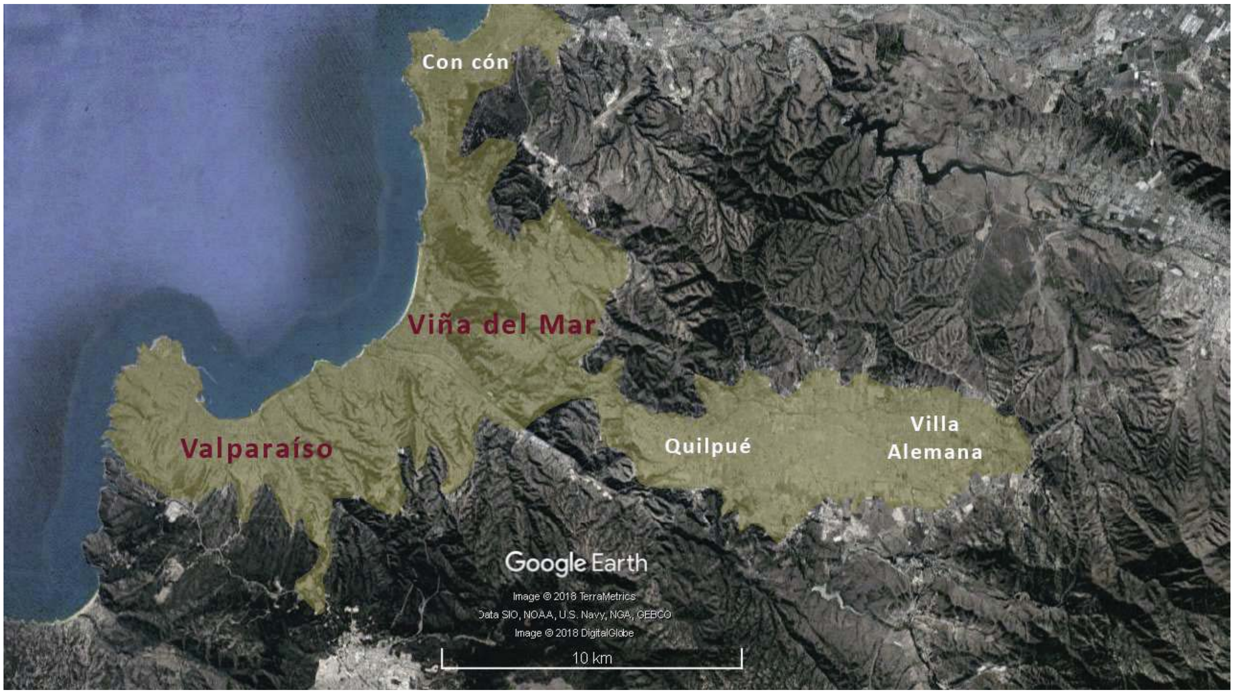


Image 5.7 *Map of Gran Valparaíso conurbation, covering 5 municipalities (comunas), of which our investigation focuses on the two largest, Valparaíso and Viña del Mar.*

growth is due in part to its proximity to the capital of Santiago (Valparaiso was declared the official port of Santiago in 1544) and in part to its cooperative topography, with a depth (12.5-13.7 meters) sufficient to allow the large commercial ships and a natural promontory in *Punta Angeles* that protects boats from the worst of the southwestern winds.

Climate

The second contextual point of our two cases is that of the climate, and here too the tectonic forces that formed the region over millions of years have resonance today. Earth's climate has several macro variables that change over time, including solar output, asteroid impacts, and the planets relation with the sun,[3] but once the sun's radiation enters the atmosphere, it also is affected by local the surface features of the earth, meaning the topography of the planet also has an influence, direct and indirect, on regional climates.

The most commonly used climate classification methodology, the Koppen-Geiger system, defines both the *Zona Central* of Chile and the entirety of the Cascadia region as having *Warm Mediterranean Climates* (csb)[4]. In this classification system a region's climate is defined by the three letters of its code:

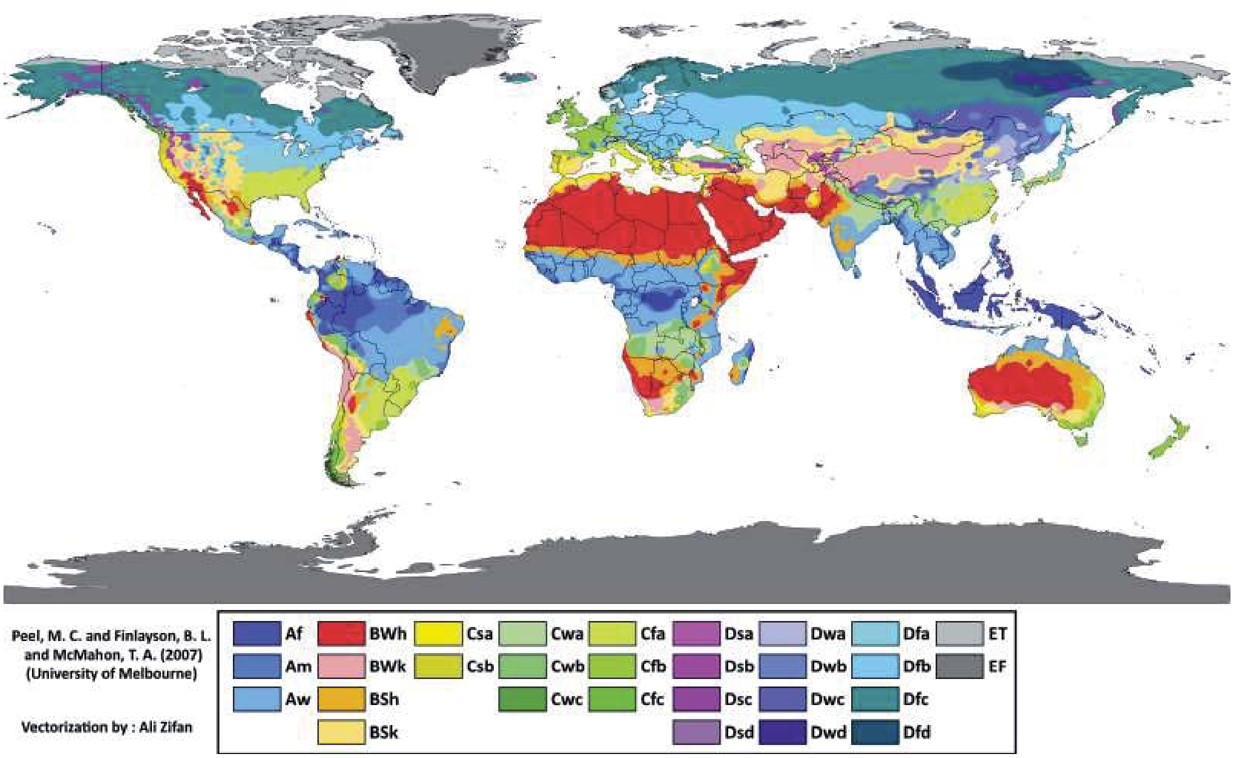


Image 5.8 *Worldwide mapping of the Koppen-Geiger climate system. Both Valparaíso and Vancouver sit in the Csb designation of Warm Mediterranean Climate. Source: Peel, M.C., Finlayson, B.L., and McMahon, T.A. [Image] 2007. University of Melbourne*

- The first letter represents the general climate type. *C* denotes a temperate climate, with the average temperature of the coldest month over 0 degrees Celsius.

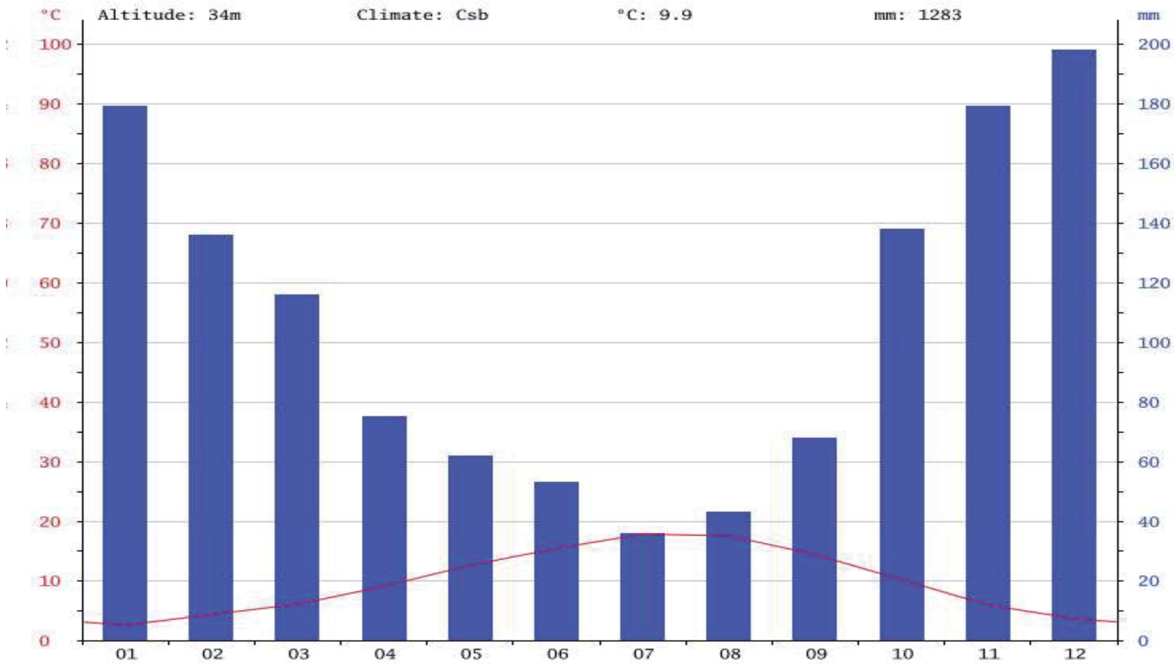
- The second letter represents the precipitation pattern. S denotes a wet winter, with three times as much rain during the wettest winter month as the driest summer month.

- The third letter represents summer temperature. B indicates a warm summer, with the hottest month of the year averaging less than 22 Celsius, but with at least 4 months averaging over 10 Celsius.

The Pacific Northwest is well known for its rainy climate, and while the reputation is not undeserved, it is commonly misunderstood. Measured in quantity of precipitation, major population hubs like Portland, Vancouver and Seattle actually receive far less than other major North American cities. According to a study done by San Francisco based Weatherbill Inc., in terms of average rainfall Seattle is actually the 41st wettest city in the United States, followed by Portland at number 42. The Northwest reputation for rainfall isn't completely misplaced however, as the same study found that Seattle was the number one city in the USA in terms of 'rainy days' per year (defined as a 24 hour period with more than .6 centimeters of rain). Indeed the average number of clear or only partly cloudy days in Cascadia varies each month, from a measly four to eight in winter months, eight to 15 in spring and fall months, and 15 to 20 in summer months (Image 5.9). The heavy rainfall in the Cascadia region can also influence the intensity of flooding during extreme weather events, as saturated water tables and backed up storm drains exacerbate already stressed infrastructure.

Cascadia owes its climate to the interaction between three main features: the topography, the influence of the Pacific Ocean, and the rotating pressure regions in the nearby North Pacific Ocean. These pressure zones (one high, one low, which trade places in the winter and summer), influence what type of wind is carried from the Pacific Ocean over the region. In the summer the high pressure system, called the North Pacific High, is dominant, and the clockwise movement brings warm westerly and north-westerly winds over Cascadia. In the winter the low pressure system, called the Aleutian Low, moves from its place farther north and intensifies, displacing the high pressure system south. The combination of these two systems sends southwesterly wind into Cascadia carrying moist ocean air that is closer to the temperature of the ocean than the temperature of the land it encounters, producing a condensation effect that intensifies as the air reaches the physical barrier provided by the Cascade mountain

CLIMOGRAPH - VANCOUVER



TEMP GRAPH - VANCOUVER

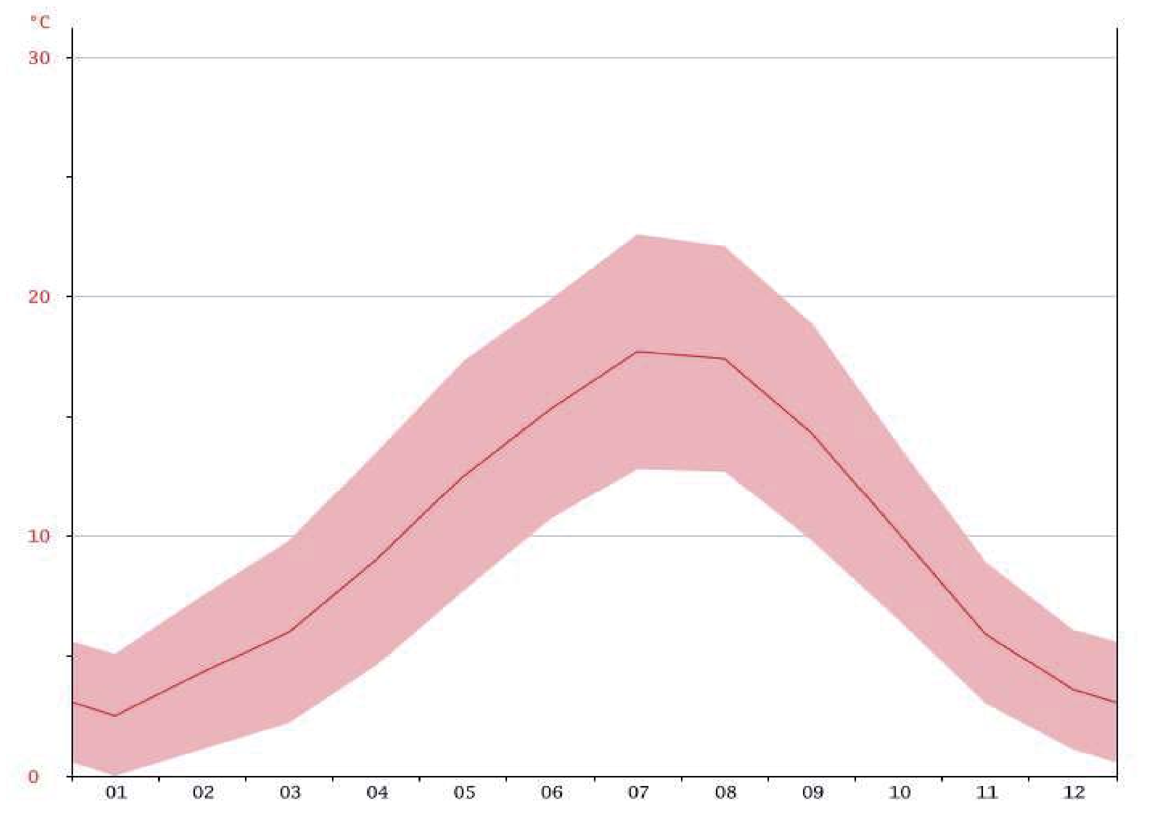
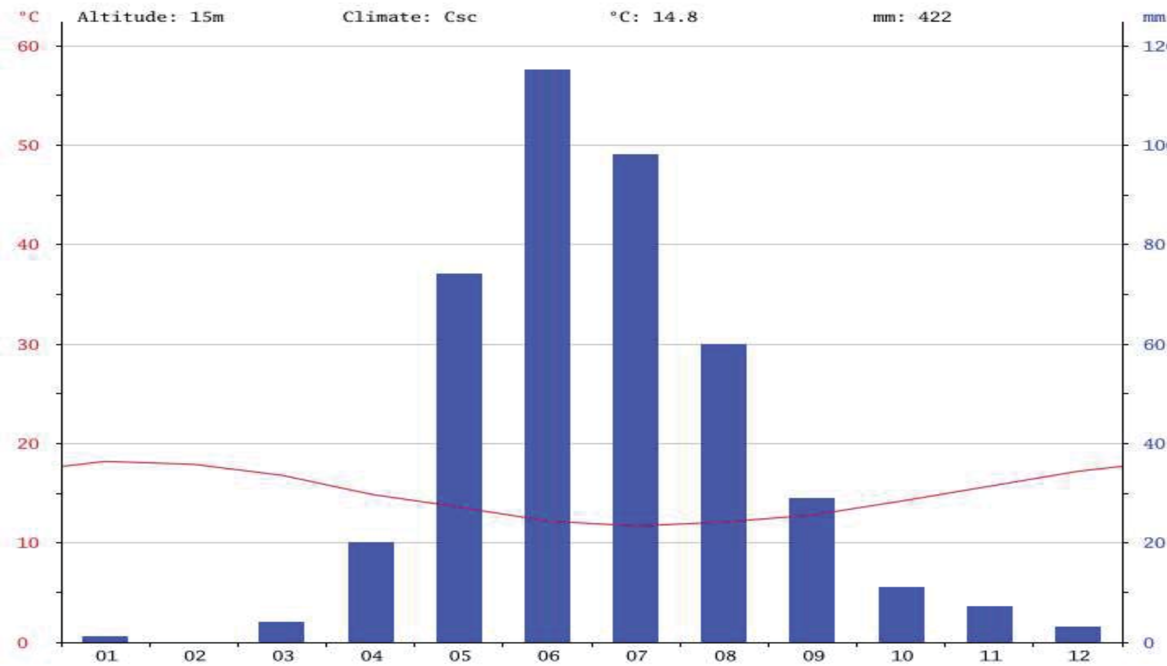


Image 5.9 *Climate and temperature graphs for Vancouver, Canada. Source: Climate-data.org. https://en.climate-data.org/location/963/*

CLIMOGRAPH - VALPARAÍSO



TEMP GRAPH - VALPARAÍSO

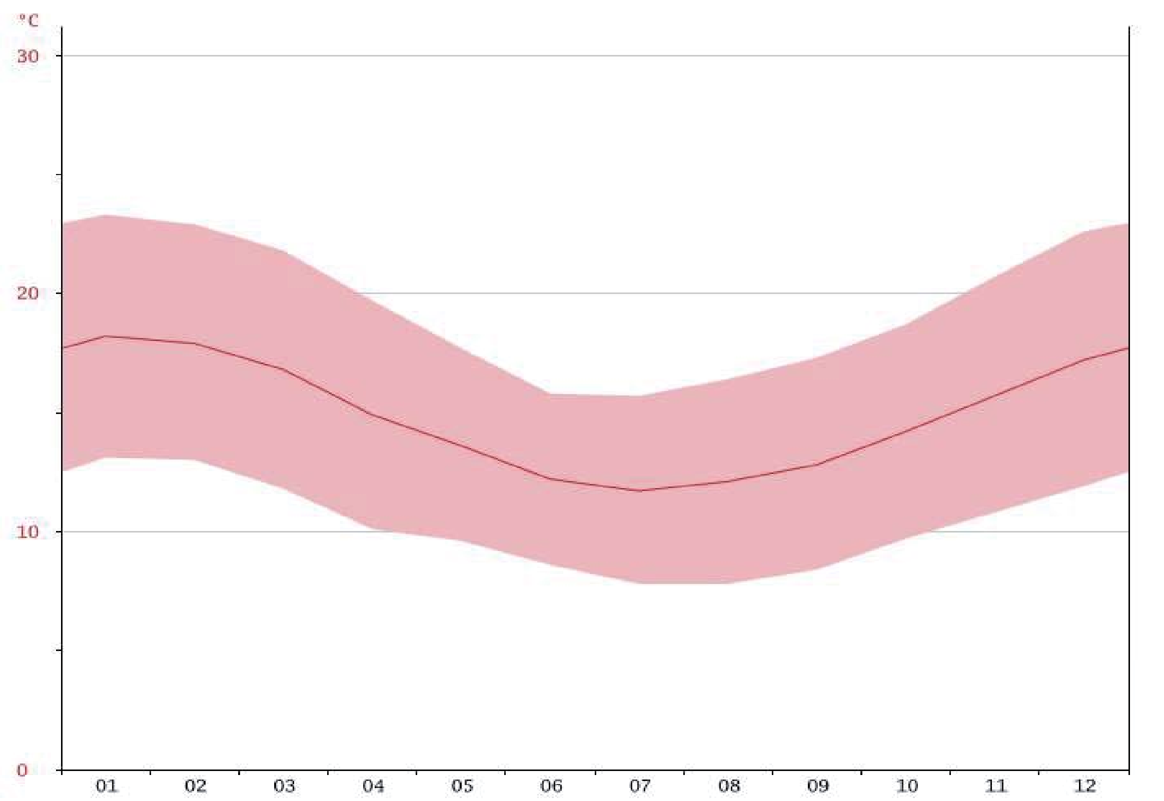


Image 5.10 *Climate and temperature graphs for Valparaíso, Chile. Source: Climate-data.org. https://en.climate-data.org/location/963/*

range. The result is a temperate climate year round with stretches of wetness that last months at a time.

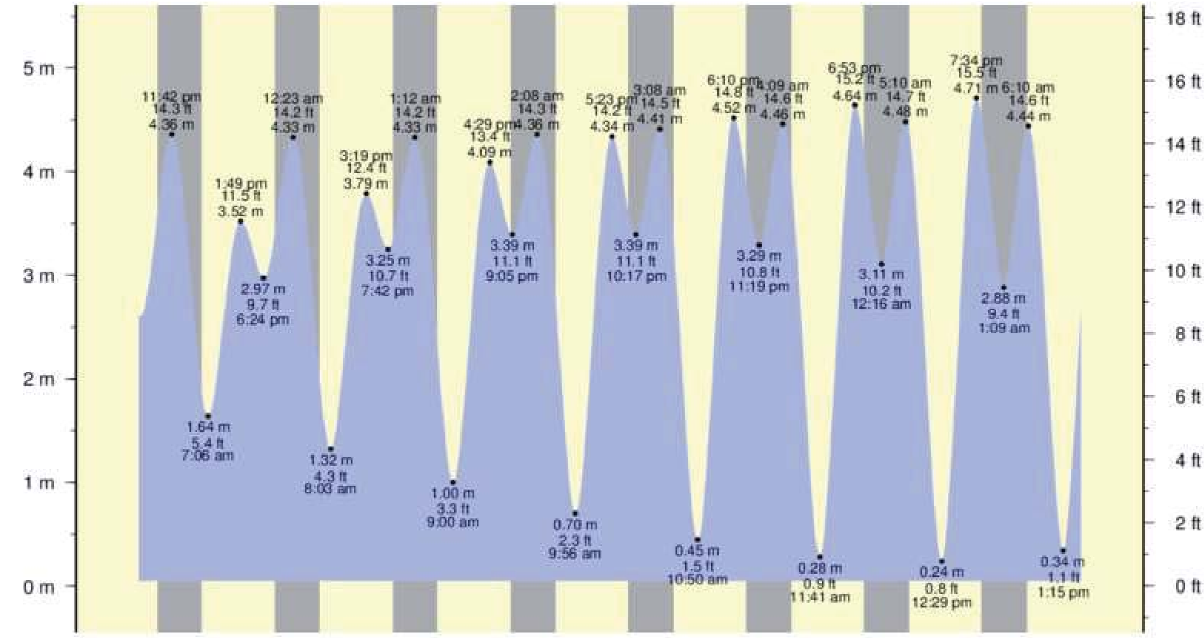
The Aleutian Low is also responsible for the most powerful storms that affect the Pacific Northwest. Colloquially called “Big Blows” and meteorologically defined as mid-latitude (or extratropical) cyclones, these storms can reach wind speeds comparable to the category 2 or 3 hurricanes that periodically devastate the Caribbean. These potent storms are driven by low pressure systems common in the North Pacific Ocean during winter months where cold air flowing towards the tropics and warm air flowing towards the poles meet, forming what is known as a polar front. Cyclones form along this polar front through a process called cyclogenesis, wherein the two bands of air moving in opposite directions create a strong horizontal temperature gradient, providing the latent energy necessary to create the strong winds associated with these storms. The aforementioned Aluetian Low pressure system sitting off the coast acts to both increase the power of the cyclones as well as guide them towards landfall in the Pacific Northwest.

Similar to Cascadia, the Zona Central of Chile derives its climate from the interaction between the ocean and the inland topography. While the Andes are the dominant geologic feature of Chile, the Zona Central included, there is another, smaller range that plays a major role in the microclimates of the region. The Cordillera Costa runs parallel to the Andes Mountains, and while much smaller in altitude (2000m vs. 5000m), it sits much closer to the coastline: in the Zona Central it ranges from 35 to 40km from the coast. The Cordillera Costa plays the role that the Cascades do in the Pacific Northwest, forcing the water laden winds coming from the pacific up and keeping the coastal region more temperate but wetter than inland areas like Santiago.

Average temperature in the region ranges between 11.4 Celsius in the winter to 17.0 in the summer, with an average of 14.2 year round. Like the Cascadia region, the Zona Central pays for its moderate climate with higher precipitation levels than its drier, more temperature volatile neighbors. Precipitation levels are highest in the winter months, reaching their maximum of 115mm in June (Image 5.10). Winds in the area primarily come from the southwest between 40 and 60 degrees south, and a shift from predominantly WSW winds to more SW direction has recently been observed, possibly due to the displacement of the South Pacific High pressure system.[5]

Sea level fluctuations

Local sea level is the major factor in the severity of coastal flooding during extreme weather events, and has several variables, both short and long term in nature. Some of the more impactful short term influences



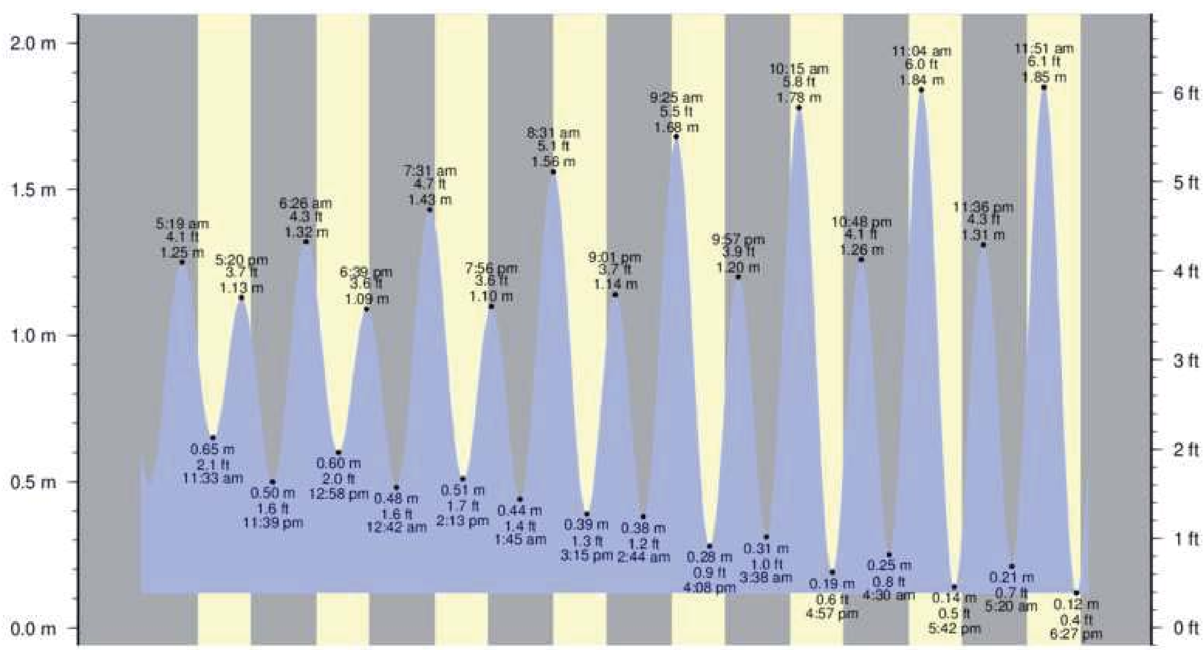


Image 5.11 *Tide charts for Vancouver (above) and Valparaíso (below). Source: https://www.tide-forecast.com/, Accessed August 5, 2018*

(pressure, wind and wave setup) are discussed in the natural hazard section, but here we look at several of the influences that are generally factored into base sea level when calculating storm surge, rather than calculated apart.

Tides

Outside extreme weather events, the most impactful component of sea level are daily tides. The tides in both Valparaiso and Vancouver are mixed semi-diurnal, meaning they have two high and low tides each day with differing maximum water levels. Winter tides are larger than those in summer, and the maximum tide comes every 18.6 years, though twice-yearly maximum tides, colloquially called King Tides, can come close. King Tides are a non-scientific name given to the perigean spring tide, the yearly event when the sun and moon align, producing extra high tides. In Vancouver especially these tides are a major contributor to flooding events in the urban area.

In Vancouver the highest recorded tidal range (difference between high and low tides of the same cycle) is 5.06 meters and image 5.11 shows a weekly tide chart for the region.[6] King tides in Vancouver can reach 5 meters above chart datum, a level that leaves the coastline extremely vulnerable to flooding, as a surge of just .6 meters on top of the tide level could result in flooding in the coastal zone.[7] Tides in Valparaiso have a much lower range, with a recorded maximum of 1.8 meters[8] (weekly tide chart in image 5.12), suggesting the overall effect that tides play on coastal flooding in Valparaiso is much less than that of Vancouver.

The measuring of sea levels along coastal areas is the provenance of each relevant national agency (NOAA in the United States[9], DFO in Canada,[10] SHOA in Chile[11]), and while the exact tools used in each case may vary, the methodology of determining the mean sea level is the same world-over. The level of the ocean is measured relative to a fixed land point hourly at stations on or near the coastline with instruments called tide gauges (also called marigrams or mareographs). The constant monitoring of the sea level fluctuation provides benchmarks for high and low tides for the area. Given the multitude of various influences that may subtly change the level of the sea, achieving a data set suitable to define a mean sea level may require years and years of information gathering. NOAA's mean sea levels for example are generated by taking the average height of all tide fluctuations from nineteen years of continuous measurement. This immense amount of data allows for a reasonably reliable estimation of the water level, without the fluctuations inherent in any small sample size.

El Niño Southern Oscillation (ENSO) and

Pacific Decadal Oscillation (PDO)

These two periodic long term climate variations of the western Pacific Ocean also affect local sea levels. El Niño and La Niña are the warm and cold phases of the El Niño Southern Oscillation, a fluctuation in temperature in the Pacific Ocean that has effects on both regional ocean processes and global weather patterns. No two ENSO episodes are exactly alike, but they generally last between nine months to a year, though extended periods have lasted years.[12] Like the ENSO, the Pacific Decadal Oscillation is a climate variation in the Pacific Ocean. There are two main points that separate the two events however. The first is that the main effects of the variation are seen mainly in the northern Pacific and the North American continent, as opposed to the ENSO which primarily affects the southern Pacific. The second is the time period over which they are active: while the typical El Niño may last a number of months, the PDO typical runs in 20-30 year cycles.[13]

Both variations are associated with warming or cooling of surface water temperature, which will raise or lower sea levels thanks to thermal expansion. This type of variation, be it local or global, is called steric sea level change, and is a result of changing density of the ocean water. These are very long term fluctuations, imparting change over many years' time, and although they can cause significant variations in sea level, in practice they are considered part of the baseline mean sea level, and for storm surge purposes are calculated as part of the astronomical tide.

Currents

The climate and livelihood of much of the west coast of the Americas depend heavily on the ocean currents that run along their coastlines. Along the western coast of the United States the dominant current is the California Current, a cool water current that branches from the North Pacific Current

Image 5.12 The two major, and one minor, currents that impact the coasts of the Zona Central in the Southern Hemisphere and the Pacific Northwest in the Northern Hemisphere

offshore of the Cascadia region and runs all the way to Baja California. In the southern hemisphere, off the coast of Chile and Perú it is the Humboldt (or Perú) Current, a cold water current that runs the length of the western coasts of both countries. Both currents draw cold water from their respective poles and move it along the coastline towards the equator, and in both cases the currents play major roles in the ecosystems and climates of the coastal regions they abut, as well as in the cultures of the human settlements that arose in those areas.

These two principal currents function very similarly and share many of the same attributes. Both currents are classified as eastern boundary currents, meaning that they are bounded by land to their eastern flanks, and both are affected year-round by a phenomenon called ‘upwelling’, a fairly rare occurrence in ocean currents worldwide. Upwelling is the replacement of warmer, shallow, nutrient depleted water from the coast with cooler, deeper, nutrient rich water farther offshore. This transfer is crucial for creating the vibrant marine ecosystems that can be found up and down the western coast of the Americas. The nutrients that the cool water brings to the coast fertilize the waters there, which in turn feed the marine life that provide sustenance for larger sea and land wildlife. It’s these upwelling areas that make the coasts of Chile and Cascadia some of the most prolific fisheries in the world.

The cool currents running along the coastlines of the west coast also contribute to the weather patterns of each region. Wind blowing across the cold water of the currents and consequently passing over the coast serves to cool the coastal areas, contributing to the year-round temperate climates found in Cascadia and the Zona Central, moderating their weather considerably compared to cities at similar latitudes on the east coast of the Americas.

Local Climate Change Effects

While it’s true that the global sea level is rising, the figure of 3.2mm per year cited earlier is a global average, and local factors, such as bathymetry and currents, play an important role in how fast or slow sea levels rise in localized areas. In Vancouver the threat posed by the rising sea is a serious concern: a study of the largest coastal cities in the world found that Vancouver ranked number eleven in terms of potential future flooding damage, with $107 million projected in annual damages by the year 2050.[14] And as noted previously, these aren’t solely concerns for the distant future, as perigean tides already reach high enough to cause flooding when combined with strong winds. In addition to the parks and recreation areas that line the coast in Metro Vancouver, over 250,000 residents live within one vertical meter of the current sea level,[15] and as the mean sea level increases, that number will only continue to rise. The fact that Vancouver sits at the mouth of the Fraser River delta further complicates matters, as flooding may come along the banks of the river as well as from the ocean coast.

In Valparaiso sea level rise is less of an immediate concern than it is in Vancouver. While it may play a role in future climate change scenarios, annual sea level rise along the coast of Chile tends to vary substantially; in some places, like Arica, it has even fallen.[16] Studies suggest that this variation is primarily due to the highly seismic nature of the Chilean coastline, which can put the variation of sea level not so much in the rise of the oceans as in the rise and fall of the coastline itself.[17] After the 2010 earthquake centered off the coast of central Chile, researchers noted a rise along much of the Chilean southern coast, small in some places, up to 2.5 meters above its previous level in the Arauco Peninsula.[18] Nor was this an exceptionally rare incident: after the 2014 earthquake in Iquique, a team of scientists used GPS to map uplift and subsidence along the northern Chilean coast, finding results that varied between 15cm of uplift at Chanabaya to 50cm of subsidence at Pisagua.[19]

Image 5.13 *The earthquake in 2010 raised the coastline all along the southern Chilean coastline. This lighthouse in Lebu, Bío Bío Region used to be isolated on a small island, but uplift created a new tidal platform. Source: Paul Duhart, Alejandro Ramos. [Photo] Servicio Nacional de Geología y Minería.*

Given the coastal sea level variation possible from a single seismic event, of which Chile experiences dozens per year, sea level rise is less of a local concern for the central coast. Rather, it’s the increase in strength mid-latitude storms could have the greatest potential impact. While the science is much less clear on the implications of a warming climate on storms than it is for the rising sea level, there have been studies suggesting that the warmer surface temperature of the oceans and the increased levels of condensation in the atmosphere will lead to more powerful mid-latitude cyclones of the type that commonly hit both the Chilean central coast and Cascadia.[20]

Climate change is also affecting the coastline of Chile on another, more gradual scale. A study found a marked increase in the number of powerful storms to hit the *Zona Central* of Chile over the past 60 years, from 5 events per year in the mid 1900’s to around 20 a year in the 2010’s, including 83 events with significant wave heights over three meters between 2015-2016.[21] The same study suggested that this rise may be contributing to increasing rates of coastal erosion along the beaches of Gran Valparaíso, combining with the development paradigms along the border to exacerbate the risk of significant change.[22]

Demographic

City of Vancouver, British Columbia

Made up of twenty-one municipalities splayed around the mouth of the Fraser River delta opening to the Strait of Georgia to the west and bounded by the Canadian stretch of the American Cordillera mountains to the east and north, Metro Vancouver covers nearly 3000 square kilometers and according to the 2016 census is home to just under 2.5 million residents[23]. Its unique location, nestled between the Salish Sea and Coast Mountains mean that available buildable land in Vancouver is permanently at a premium, so new development tends to go up rather than out. This has led to the municipality of Vancouver having the highest population density in all of Canada, at nearly 5,500 persons per square kilometer, and of the top ten densest municipalities in Canada, Metro Vancouver holds four[24].

The city of Vancouver is the economic center of western Canada, driven primarily by its port activity. Serving as Canada's gateway to the Pacific, the port of Vancouver is Canada's largest and the third largest in North America according to total tonnage.[25]

Image 5.14 *This view of False Creek highlights emphasizes the city's priveleged setting between the mountains and the sea. Source: Tourism Vancouver. [Photo] Retrieved from https://www.tourismvancouver.com/*

It does over 200 billion worth of trade per year with over 170 different countries, and serves as the backbone of the western Canadian economy.[26] Beyond purely economic effects, through its exposure to peoples and cultures around the world, the port has played a major role in defining the city of Vancouver as one of the world's most diverse metropolitan areas.

Huddled as it is between the sea and the mountains, Vancouver's idyllic setting is a major draw to tourists looking for outdoor activities, and in 2016 over 10 million people visited the city, contributing over 4 billion USD to the local economy and providing 70,000 full time jobs.[27] In addition to Whistler Mountain, a world renowned ski resort located a short drive away, Vancouver is in close proximity to several national parks and nature reserves, as well as popular destinations like Vancouver Island. Vancouver's port also plays a major role in the regions robust tourism industry, as it plays temporary home to over 230 cruise ships annually, either as a final destination or a port of call for the ships on their way up or down the coast to visit the glaciers and fjords of Alaskan.[28]

Gran Valparaíso, Zona Central

Composed of five municipalities spread out along the coast and the interior, Gran Valparaiso is home to just under 1 million

Image 5.14 *The city of Valparaíso wraps around Valparaíso Bay, forming a natural amphitheater and reinforcing the importance of the relationship between city and sea. Source: 24 Horas. [Photo] Retrieved from http://www.24horas.cl/nacional/asi-se-ven-vina-del-mar-y-la-bahia-de-valparaiso-desde-el-aire-1803746*

persons in 700 square kilometers of land, according to the 2017 census.[29] While the tendency for most of the 20th century has been a steady flow of emigration from Chiles regions (including Valparaiso's V region) to the capital city Santiago, according to analysis of the 2012 census, Valparaiso inverted this trend in the last decade. The flow from other regions of Chile, especially the south, has stayed steady, but instead of seeing the expected decline, Gran Valparaiso actually saw its population grow by 7.5%, the highest rate of growth of any urban area in Chile. And that growth isn't expected to slow anytime soon: the population of Gran Valparaiso is expected to grow to 1.2 million inhabitants by the end of the decade.[30]

Although the total area of Gran Valparaiso stretches inwards towards the coastal mountain range, the heart of the conurbation is on the coast, seated in the hills and flatlands that surround the Bay of Valparaiso. The development of the city, in the past and today, is tied strongly to the port located at the foot of the sloping hills of the city of Valparaiso. From its initial settlement by Europeans in the 16th century, the port of Valparaiso quickly developed into the most important anchorage in Chile, and one of the major stops in the worldwide shipping trade that dominated the 19th century. Its meteoric growth is due in part to its proximity to the capital of Santiago (Valparaiso was declared the official port of Santiago in 1544) and in part to its cooperative geography, with a draft (12.5-13.7 meters) sufficiently deep to allow the ingress of large commercial ships and a natural promontory that protects the boats in the harbor from the worst of the southwestern winds and waves that are the most common in the zone.

The magic of Gran Valparaiso is that of an urban area tied unmistakably to the sea that abuts it. Despite the fact that the economy of the region has diversified since its days as one of the premier ports of the world, today the relation between the Zona Central and the ocean remains fundamental. Tourism, one of the sectors of the economy most important to the region today, depends heavily on the relation between the urban and the ocean, with nearly 70% of the overnight visits in the region occurring in the coastal area of Gran Valparaiso (Valparaiso, Viña del Mar, Concon).[31] Like Vancouver, the port of Valparaiso maintains a crucial role in the tourism industry as well: in the 2015-1016 tourist season the dock dedicated to cruise ships welcomed 27 ships and nearly 94,000 passengers.

Natural Hazards

The homogeneity in the topography and geography of the west coast of the Americas, and their placement within the large scale weather-geologic system of the Pacific coastline means that they experience many of the same truly disruptive natural hazards that, when they occur in proximity to human

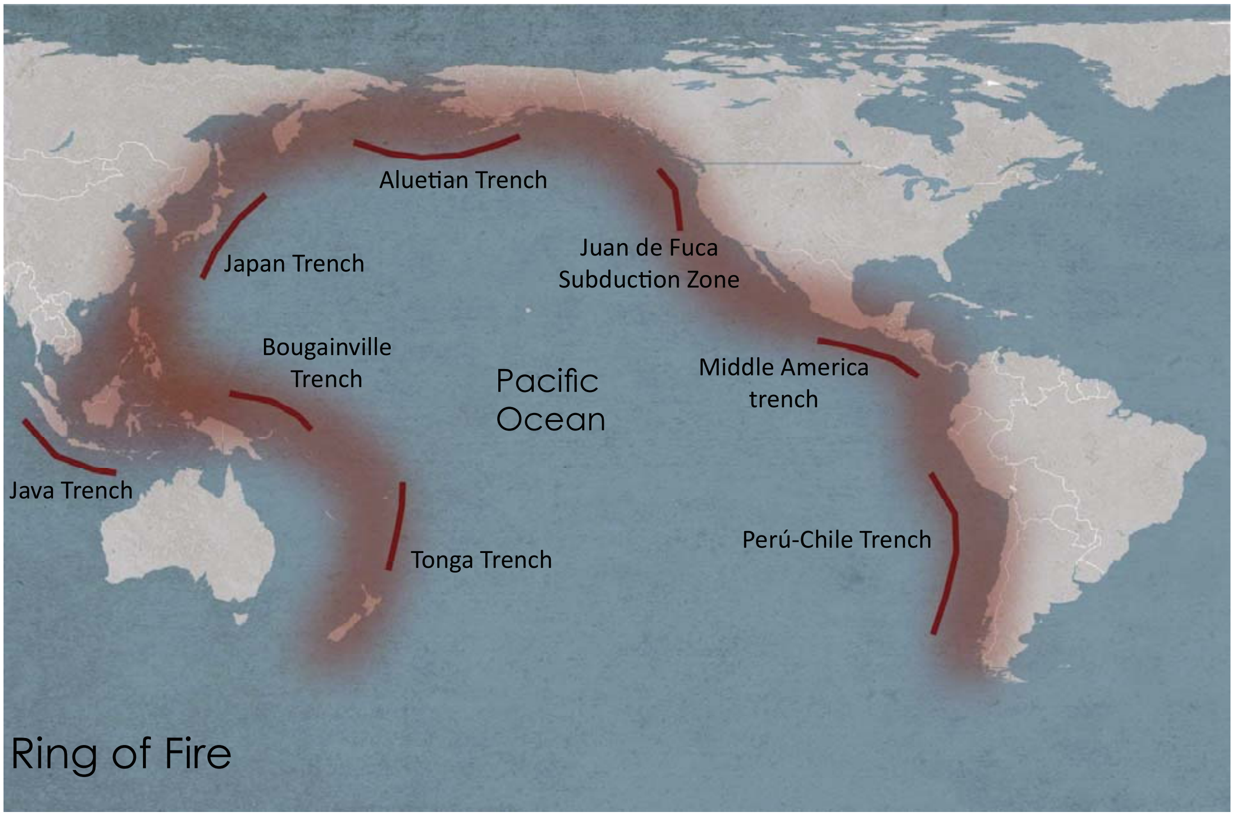


Image 5.14 *The Ring of Fire derives its name from the high number of active volcanoes and tectonic faults that surround the Pacific Ocean. Earthquakes, tsunamis, and volcanic eruptions are all hazards that occur with some frequency to the countries that sit along the border.*

settlements, become what we call natural disasters[32]. The most influential of these shared events experienced in the west coast of the Americas are earthquakes, tsunamis and coastal storms. Each of these natural phenomena may occur independently of each other, but within the greater geologic/ weather system of the Pacific coast, their interplay becomes critical to understanding the adaptation solutions best suited to address their ever-present threat.

Earthquakes

The tectonic plates that form the western border of the Americas are part of a larger system that encircles the entirety of the Pacific Ocean, often colloquially called the Ring of Fire. The name is derived from the copious number of volcanos, many still active, that were formed by the same orogeny that gave rise to the American Cordillera. The plates that form the ring are constantly in motion, resulting in a series of combustible borders which produce around 90% of the seismic activity worldwide[33]. Of the 17 most powerful earthquakes in the world since 1900, only 1 has not been in the ring of fire[34].

As noted previously, currently around 36% of the world's populations lives within 100kms of a coast, and in the countries that make up the ring of fire, that number is even higher.[35] In Chile, 78% of the population lives within 100km of the coastline, while in Japan that number jumps to 99%.[36] The concentration of people living so closely to the areas most affected by the moving tectonic plates creates a situation in which earthquakes represent a real and daily threat to hundreds of millions of lives, and one that the process of urbanization is intensifying.

In 1906 a movement in the border between the Pacific plate and the North American plate (the San Andreas Fault) resulted in 3,000 deaths and over 80% of the city of San Francisco going up in flames.[37] At the time of the earthquake, the city had a population of 342,782 in 53,323 homes, half of which were homeless after the earthquake and the fire that followed.[38] Today, the San Francisco Bay Area is home to 8.7 million, and while the current city of San Francisco has a much smaller population of 800,000, they are crammed into only 124 square kilometers, making it the second most densely populated city in the USA, apart from New York. An earthquake of equal or more force than that that struck the city in 1906 could be catastrophic for the region, as was recently imagined in the 2015 blockbuster *San Andreas*. Even in areas and cultures prepared for natural hazards, the results can be devastating. When a 9.1 earthquake struck Japan in 2011 it left more than 18,000 dead or missing, in a country whose building codes provide the basis for seismic focus designed across the globe.

Seated as it is along the subduction boundary of the Nazca plate beneath the South America plate, Chile has one of the highest rates of seismicity in the world: every decade since 1900 has recorded an earthquake of at least 7.0 on the Richter scale. Despite the frequent seismic events experienced in Chile, experts predict that built up pressure along the tectonic border will lead to an even larger earthquake, 8.7 or higher, within the coming decades.[39]

While Vancouver also lies along a subduction zone, it is much less seismically active than Chile. For decades it was assumed that the lack of recorded history of earthquakes in the region meant that the Cascadia Subduction Zone did not have the power necessary to produce massive scale earthquakes like the ones in Chile experienced in 2010. More recent studies, both geologic and sociologic, have shown that the faults in the Northwest have a prolific history of major earthquakes, and projections today predict an 8.2+ earthquake has a 1-in-3 chance of striking in the next 50 years.[40]

Tsunami

In the ring of fire, the danger of an earthquake extends beyond the immediate destruction brought by the movement of the earth or the fires that often follow.

Image 5.15 *The 1906 San Francisco earthquake and following fire devasted the city, leaving half the population homeless. California has subsequently adapted its building codes to the challenge of living in a highly seismic setting. Source: AP Photo. [Photo] 1906. Retrieved from https://www.sfgate.com/bayarea/article/SAN-FRANCISCO-1906-quake-toll-disputed-2738704.php*

Image 5.16 *Like other countries in the Ring of Fire, Chile must contend with hazards from multiple sources. Rather than the shaking of the earthquake in 2010, it was the ensuing tsunami that caused the most damage in places like Dichato, Chile. Source: Juan Eduardo Lopez, El Mercurio. [Photo] 2010. Retrieved from http://www.emol.com/especiales/2010/fotos_AD/terremoto_chile_aereas/*

Another result of the shifting tectonic plates can be massive waves that move thousands of kilometers from their epicenter to strike at distant shores. Tsunamis are the waves produced by disturbances in a body of water, the most common of which is the movement of tectonic plates, but may also include meteorite impacts, landslides, or submarine eruptions. Once the disturbance occurs, the waves of the tsunami spread in all directions from the epicenter, towards the nearest land. The manner in which the wave makes landfall depends in a large part on the topography of the coastline because the velocity of the wave is tied directly to the depth of the water in which it moves. Waves move faster when the distance between the surface of the water and the floor of the ocean is greater, and move slower when the distance is less. In other words, a wave's height is directly tied to its speed: the faster a wave is moving, the lower its total height will be. A wave in the middle of the ocean will be low but fast moving, but that same wave, as it approaches the coast will slow and grow in height.

Because of the frequency of seismic activity in the ring of fire, tsunamis on the west coast of the Americas are an ever present danger. Of the 531 deaths caused by the powerful 2010 earthquake off the coast of Chile, 153 were a direct result of the ensuing tsunami, the majority of which were concentrated in the south and center-south zones of the country.[41] Other seismic events in Chile, such as a 2014 8.2 earthquake off the coast of Iquique also triggered a tsunami in the northern part of country, sparking evacuation notices along the coast. The damage was comparatively minor, and there were no direct fatalities reported from the tsunami but the experience displays the threats associated with seismic events in Chile goes well beyond the initial shaking of the earth. Tsunamis striking the west coast of North America are a much rarer event (outside of Hawaii), and tsunamis in

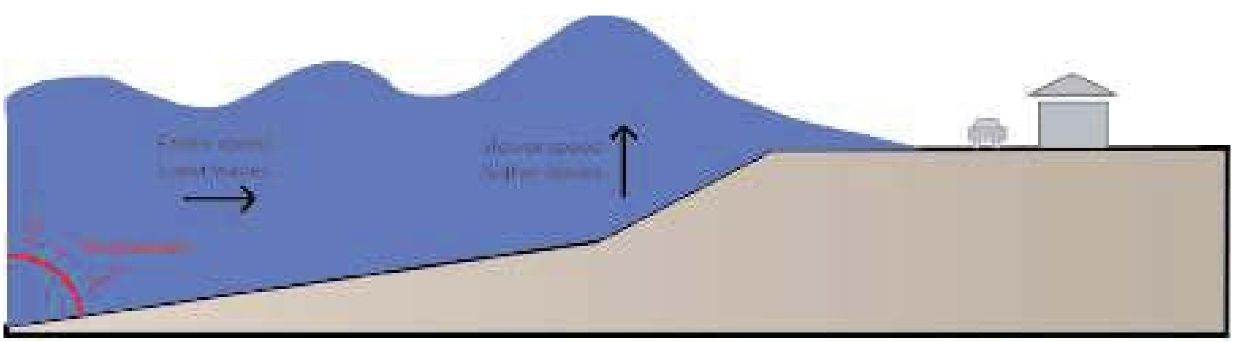


Image 5.17 *Tsunamis are byproducts of disturbances in bodies of water, and are especially relevant in an area like the ring of fire where undersea agitations are common. In deep water the waves created move faster but are smaller than when they approach land, at which point they slow but gain in size.*

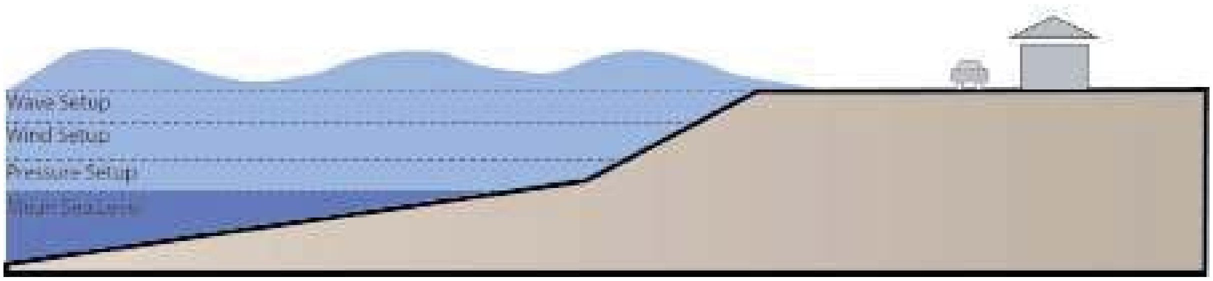


Image 5.18 *Storm Surge components. Although it appears monolithic, storm surge is calculated as a combination of several different factors. Pressure, wind, and wave setup are all short term variables that, along with local bathymetry and coast shape, will determine the size of the storm surge.*

the Pacific Northwest are even scarcer. In such a case, massive destructive produced underwater many miles away may come ashore with little warning for those on the coast. Such was the case for the Native Americans that lived on Vancouver Island in the year 1700. Although no written history of the region exists of that time, geologic evidence and oral history from the indigenous tribes suggest that the last mega earthquake that struck the region caused a tsunami so powerful it caused serious damage in Japan 10 hours later. Closer to the epicenter, the wave hit land just 15 minutes after the earthquake, and the result was the near eradication of coastal communities, such as the Pachena Bay tribe of Vancouver Island.[42]

Storm Surge

In a study of the climate change impacts to US coastlines, the team overlaid trends of sea level rise over the past 40 years with trends of storm surge over the same time frame to see which areas will be most affected. While their study makes it clear that all SS levels will eventually be affected by SLR, the interesting finding is that the areas that currently have the lowest levels of SS (such as the Pacific NW) will actually be those where SLR has the most immediate and *proportionally* significant changes. This suggests that the areas least prepared for the impact will be those most immediately affected.

In the coming years, major amounts of SLR will have dramatic and catastrophic effects worldwide. In the much closer future however, the smaller amounts of SLR will begin to be felt immediately in coastal communities mainly through its influence on storm surge levels.

Storm surge is the difference in water rise during a storm, beyond that of the normal astronomical tide.[43] Commonly associated with hurricanes, cyclones, typhoons, or other extreme weather events, storm surge is frequently the most damaging attribute of these storms, and also the most directly affected by climate change. While an approaching storm surge appears as a monolithic wave of water, in reality it is composed of a number of layered short and long term components, each of which has its own set of independent. We previously explored how tides, a short term variable, and ENSO/PDO, the long term variables, affect sea level, so here we will examine the short term components that form storm surge and are measured separately from mean sea level when calculating storm surge levels.

Pressure set-up

A storm surge starts with the confluence of water and wind circulation during a storm; wind pressure circulating around the eye creates a vertical circulation in the body of water. In deep water, the circulation is generally undisturbed and there is little indication of the rise. As the storm approaches the coast however, the seafloor disrupts the vertical circulation of the water, forcing it up and creating the pressure set-up.

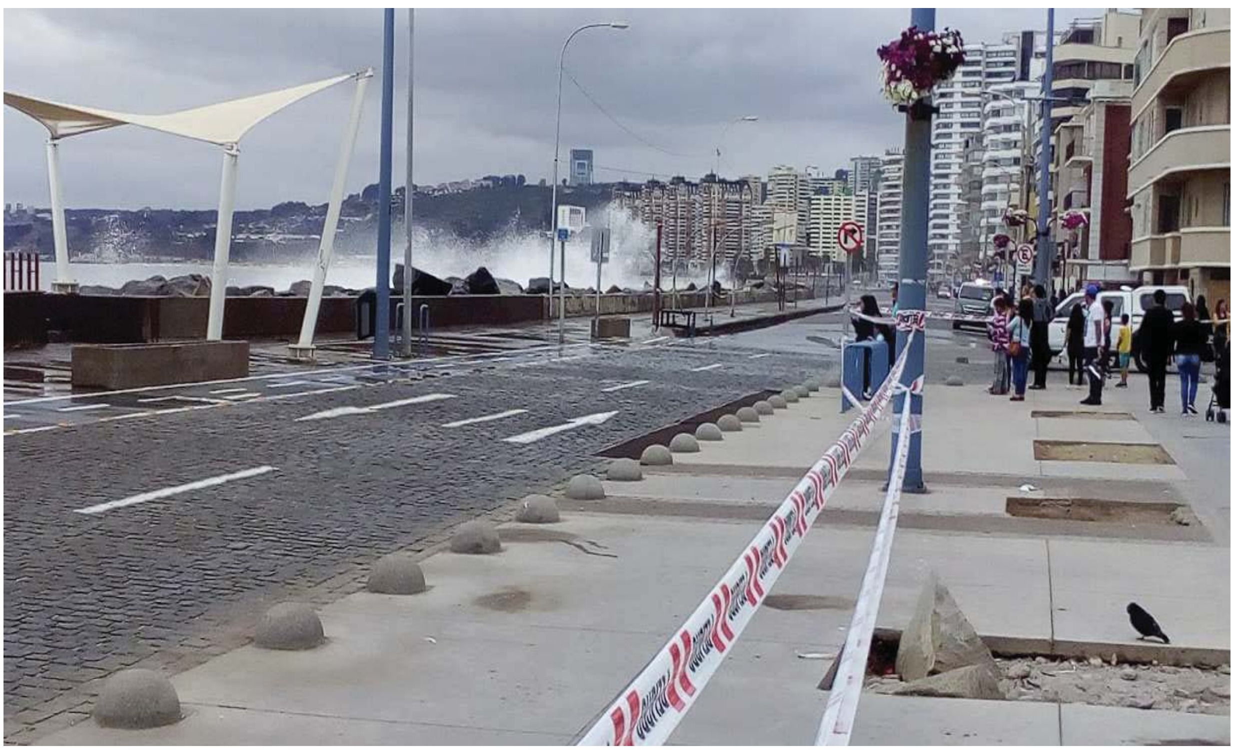


Image 5.19 *Storm Surge at Avenida Perú in Viña del Mar can overtop the coastal defenses and cause the popular seaside avenue to be closed to foot traffic for safety precautions. Source: Photo by author, Jan 21, 2018.*

Atmospheric pressure at sea level has an inverse relationship with the mean sea level: as the atmospheric pressure drops, the mean sea level rises, at about a 1 to 1 ratio. As low pressure centers move closer to land, the mean sea level will rise along with them, increasing the chance of a damaging storm surge.

Wind set-up

As wind blows over a body of water, the interaction of the moving wind against the surface of the water creates a friction, wind shear, which subtly pulls at the water. Even with small amounts of shear, the overall integrated effect over a large body of water can result in an increase of water level on the leeward side, creating the effect of wind setup.[44] During a storm, and especially as the water meets a landmass, this effect is enhanced, resulting in mean water levels higher than normal.

The first unknown variable in the equation is U, average wind speed in miles per hour. The next is fetch distance in miles. The fetch is the uninterrupted distance over a body of water over which wind is able to blow. Intuitively, storms with larger distances between the eye and the extremes can generate larger waves since the longer fetches allow for greater friction buildup. Finally, the depth along the fetch distance is measured to account to for the relationship between wave speed and water depth.

While different naming and intensity-classification systems exist for storm around the world, the most commonly used system for classifying storms in the Caribbean, Atlantic and north Pacific oceans is the Saffir-Simpson Hurricane Wind Scale. The Saffir-Simpson wind scale classifies storm events as hurricanes level 1-5 based off of their observed windspeed. Storms with windspeeds between 74-95 miles per hour (mph) are classified as level 1 hurricanes, with level 2 storms showing speeds between 96-110 mph, level 3 between 111-129, level 4 between 130-156, and level 5 hurricanes having winds 157 mph and above.

Until 2009 the scale was known as the Saffir-Simpson Hurricane Scale, and predicted pressure and storm surge as well. The predicted storm surge results of that scale however were often well off their mark,

Image 5.20 (following page) *Photo A) David Lam Park in Vancouver flooded during a King Tide. Source: Edouard de Marenches. [Photo] January 4, 2018. Retrieved from https://www.vancourier.com/news/city-of-vancouver-wants-your-king-tide-photos-1.23136320. Photo B) Avenida Perú in Viña del Mar dealing with excess water from storm surge. Source: Photo by author, January 21, 2018. Photo C) Estero Marga Marga in Viña del Mar flooding due to excess rains during a storm front. Source: Saavedravera. [Photo] July 13, 2016. Retrieved from http://www.adnradio.cl/noticias/nacional/estero-margamarga-amenaza-con-desbordarse-en-vina-del-mar/20160713/nota/3187927.aspx. Photo C) False Creek in Vancouver flooded during a King Tide. Source: CTV.[Photo] January 6, 2018. Retrieved from https://www.castanet.net/news/BC/215588/King-tide-causes-flooding*

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due to the outside factors (most specifically local bathymetry) that end up effecting storm surge size. For storm predictions in the USA for example, the Saffir-Simpson scale is used to purely measure windspeed, while the storm surge predictions are made by a separate modeling system maintained by the National Hurricane Center, part of NOAA. This model, officially named Sea, Lake, and Overland Surges from Hurricanes (SLOSH) takes into account the factors missing from the Saffir-Simpson Scale.

Wave set-up

Similar to action of the wind on the surface of the water, the constant action of waves against a shoreline also serves to gradually raise the mean water level. As the waves break against the shoreline, not all of the energy is transferred back to the main body of water. Over time, as the energy builds up along the coastline, the water level closest to shore also rises.[45]

Coastal Flooding

While coastal flooding is a direct byproduct of storm surge, storms are not the only way flooding can occur. In North America floods account for almost 20% of all natural disasters and in South and Central America that number jumps to 40% (this includes all flooding, not just coastal flooding). Together, storms and flooding are far and away the most prevalent disasters in the Americas and worldwide, making up over 60% of disasters in Central and South America, and nearly 90% in North America.[46] This high figure is partially due to the fact that flooding is often a secondary result of other weather patterns. Periodic inundations brought on by extreme tides and rising sea levels are an increasing threat in low-lying urban areas, and one of the major causes of damage from natural hazards.

Flooding can also occur in coastal urban areas thanks to weather events that may not necessarily involve a large storm surge, but are accompanied by extreme levels of precipitation. The extratropical cyclones that affect the Pacific Northwest are notorious for being accompanied by heavy precipitation and are most common in the already rainy winter season, stressing local drainage systems beyond their ability to respond. Rain falling on soil already saturated is especially dangerous, resulting in trees falling, landslides, and even sinkholes in heavily populated urban areas. As steady rainfall accumulates during the wet winter months, it can result in a higher general water table, which, when inundated with heavy rainfall during the storm produces a widespread saturation of surface material.[47] Combined with the generally hilly terrain in the coastal regions of the west coast of the Americas, this amounts to perfect conditions for producing landslides. While central Chile does not receive nearly the rainfall of Cascadia, heavy precipitation can cause drainage and flooding problems as well. Of particular note is the municipality of Viña del Mar, which sits at the mouth of the River Aconcagua. During storms the river can rise, backing up storm sewers and flooding streets across the tourist city.

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VI-CASE STUDIES

In order to understand the nature of the threats posed by extreme weather events to the functioning of the coastal border, we will examine recent incidents that have caused particular damage in both cities. The events are the following:

Vancouver

-December 15th, 2006 “Hanukkah Eve Storm”

-December 17th, 2012 “King Tide Storm”

Valparaíso

-August 8th, 2015 “Meteotsunami”

Hanukkah eve storm 2006

Characteristics

The storm known as the Hanukkah Eve Storm affected Cascadia on December 14th and 15th of 2006. Meteorologically defined as an extratropical wave cyclone, it developed over the Northeast Pacific Ocean then moved easterly, eventually crossing over Vancouver Island and into southern British Columbia. The storm brought with it three distinct weather fronts that battered the entire Cascadia region with record setting wind and rain.

The Oregon coast saw windspeeds reaching 97.1 miles per hour (156.2 kilometers per hour), while even areas farther inland such as Seattle Tacoma International Airport (SeaTac) saw speeds of 70 mph (112 kmh), both of which were the highest on record since the 1962 Columbus Day storm.[1] The storm also brought with it unexpectedly heavy precipitation during a month already notable for being an outlier in regards to rainfall. December of 2006 was on track to receive about 170% of normal rainfall, saturating the local water tables and destabilizing the soil across the region.[2] Even a small amount of precipitation could have caused a fair amount of damage, but the amounts received were far from normal. In one hour, SeaTac received 7.9mm of

City	State/Province	Weather Station	Windspeed (mph/kph)	Precipitation (24hrs)
Portland	Oregon	DPDX	53/85.3	23mm
Olympia	Washington	KOLM	53/85.3	41mm
Seattle	Washington	KSEA	69.1/111.2	39mm
Victoria	British Columbia	CYYJ	40.9/65.9	26mm
Vancouver	British Columbia	CYVR	59.1/95	16mm

Table 6.1 *Comparison of windspeed and precipitation levels for several key cities within Cascadia region.*

precipitation, while farther north at Boeing field, they measured 48.8mm of rain over a 24 hour period[3]. The levels of precipitation, both during and before the storm, played a major role in the casualties and property damage reportedly throughout the region.

Damage

Damage in Vancouver was primarily centered in the Stanley Park area, where winds gusting at 97.6 mph (157 kmh) toppled around 10,000 trees across 41 hectares[4]. The waves battered the park's famous seawall walkway, throwing debris six meters into the air, causing extensive damage to the pavement and retaining wall and causing the Lions Gate Bridge connecting the park to downtown Vancouver to temporary close in the morning due to trees blocking its access routes.[5] Downed trees on power lines cut electricity to about 250,000 homes and 100 stoplights, interrupting the next day's commute[6]. Ferry service between Vancouver Island and the city of Vancouver was temporarily stopped as a result of a barge colliding with a ferry berth[7].

The United States portion of the Cascadia region was hit even harder. Like in Vancouver, falling trees were responsible for a large portion of the overall damage. Downed trees blocked roads across western Washington and knocked out power lines to nearly 1.5 million households[8]. Uprooted

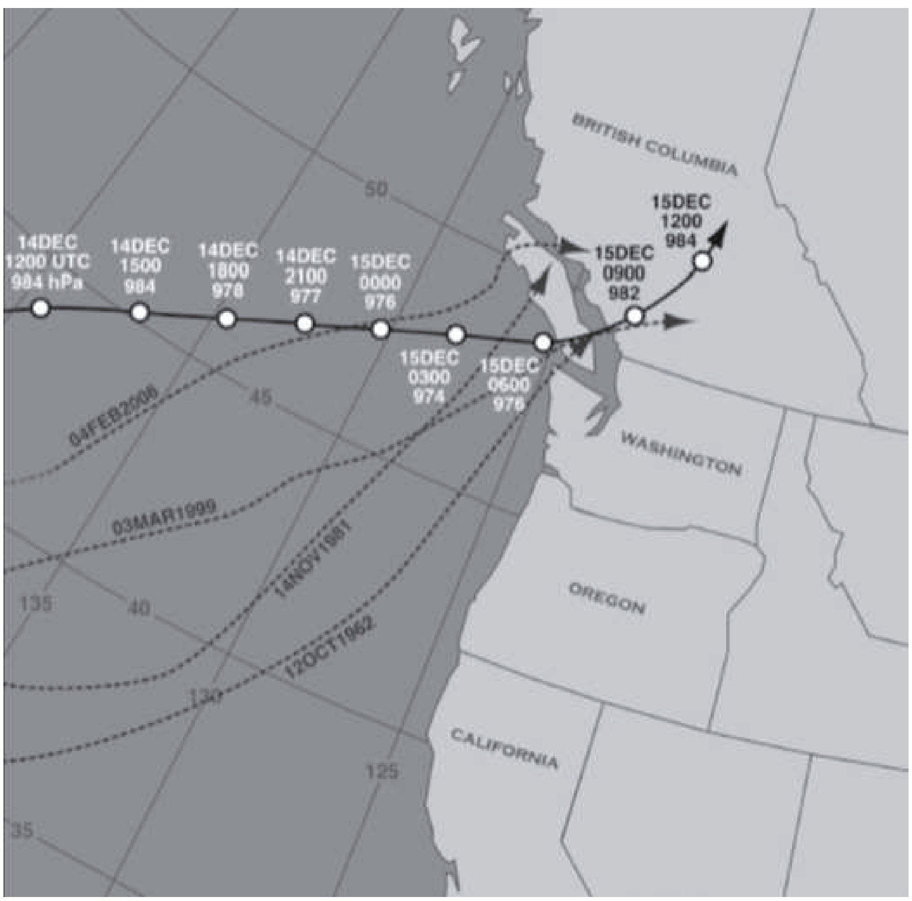


Image 6.1 *The path of the Hanukkah Eve Storm, as well as several other historically powerful regional storms (dotted lines). The Hanukkah Eve storm tracked over the southern tip of Vancouver Island before turning northwards just past Vancouver. The winds that accompanied the storm were intense, but the directionality spared Vancouver coastal areas from the worst of the waves, instead the areas trees bore the brunt of the storm effects. Source: Read and Reed, "Hanukkah Day"*

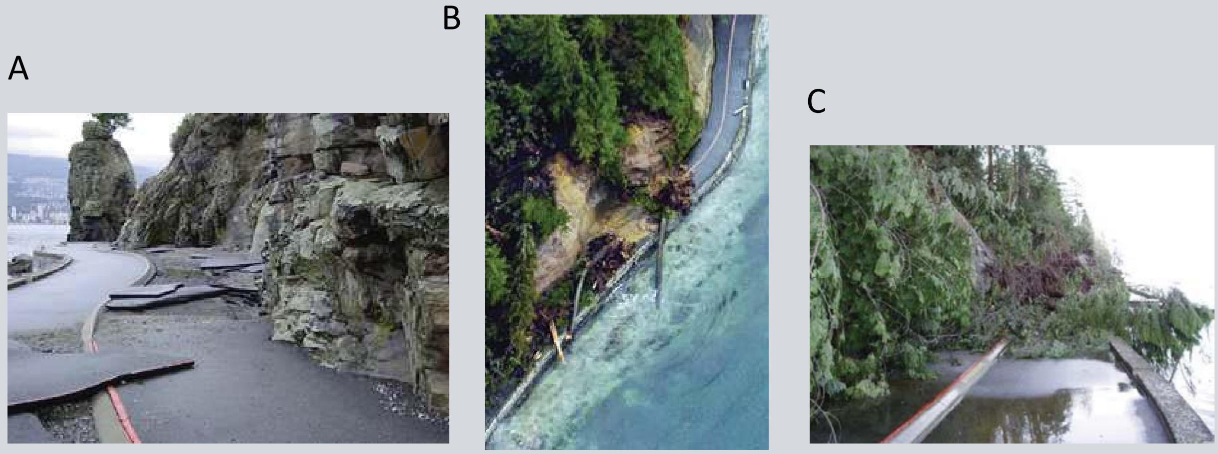


Image 6.2 *Photo A) Debris and waves caused asphalt along the seawall to loosen. Source: City of Vancouver. [Photo] 2006. Retrieved from https://globalnews.ca/news/3123909/watch-10-years-since-major-windstorm-hit-stanley-park/. Photo B) Downed trees damaged the seawall in Stanley Park. Source: Jason Payne. [Photo] 2006. Retrieved from http://www.windsorstar.com/business/Photos+2006+windstorm+Stanley+Park/5861528/story.html. Photo C) Trees and other damage to Stanley Park caused the first park closure in 40 years after the storm. Source: Paul Lawson. [Photo] 2006. Retrieved from http://stanleyparkecology.ca/2016/11/01/wake-windstorm-new-way-forward-spes-stanley-park/*

trees can be a danger in any wind event, especially one as powerful as this one, but the extremes that this storm saw were mostly due to its timing, arriving as it did during an exceptionally wet month that had already seen several lesser storms hit the region, leading to the highest one-month totals of precipitation in numerous areas throughout Cascadia. The accumulated effect of the rain brought by the storms was an elevated local water table and highly saturated topsoil, reducing cohesion and shear strength of trees across the region[9].

The rain also brought serious infrastructure problems in western Washington. The Washington State Department of Transportation (WSDOT) reported 88 roads and highways in total suffered some form of closure, including Interstate 5, the main freeway connecting the entire western seaboard of North America. According to analysis of the closures by Read and Reed, the roads were closed for the following reasons: 67% for fallen trees and rocks; 10% for downed power lines and flooding; 6% for high crosswinds; 17% for mudslides, traffic light failures and accidents[10]. The Tacoma Narrows Bridge (famous in its first incantation for collapsing under heavy winds in 1940) was also closed for the duration of the storm.

Another infrastructure failure was brought about by the precipitation when overloaded sewage treatment plants discharged raw sewage into the adjacent Puget Sound.

Casualties

There were 14 known fatalities in Washington State and hundreds of reported injuries.[11] The main culprit was in both categories was carbon monoxide poisoning. After the power failure many families, especially immigrant families, used outdoor stoves or generators indoors in order to stay warm in temperatures that, in some cases, dropped below zero. 8 deaths were directly attributed to this, as well as over 250 non-lethal cases that were reported to local hospitals over the course of the two day storm[12]. Falling trees also were responsible for a number of deaths, either via direct impact or secondary causes, such as road blockage. One death in Seattle was caused by a backed up runoff system that flooded a woman's basement and led to her drowning.[13]

Cost

In Vancouver the repairs to park and seawall cost upwards of 10 million US dollars[14], and there were around 80 million US dollars of insurance claims made in response to the storm. In the US insurance claims rose to 220 million dollars, across over 57,000 individual claims[15].

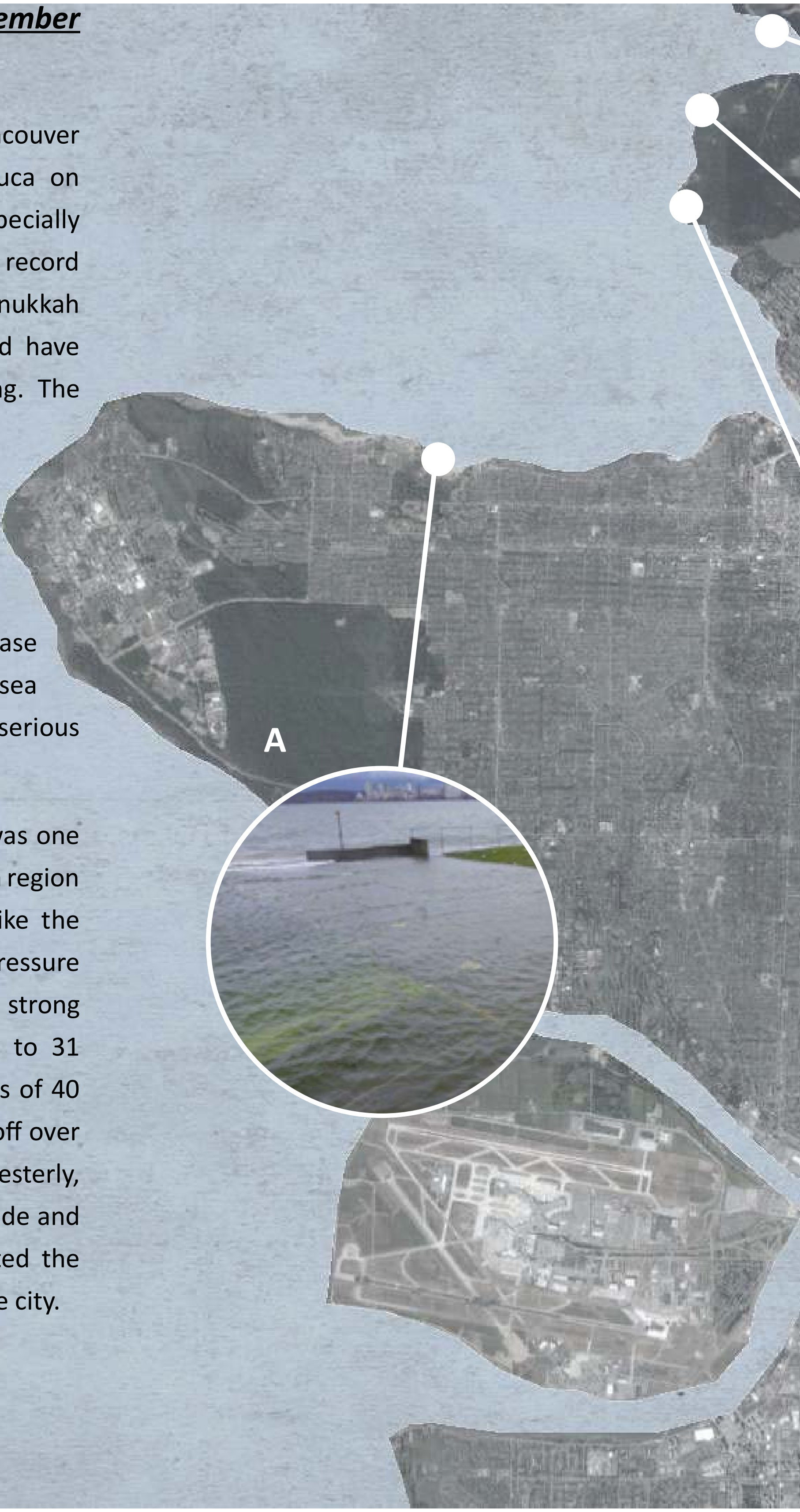
Analysis

The Hanukkah Eve storm was one of the most powerful windstorms to strike Cascadia in the last half century. Strong winds and exceptionally heavy rain were the hallmarks of the storm and while they caused extensive damage and casualties across the entire region, the damage was almost exclusively as a result of secondary results (downed trees, carbon monoxide poisoning, etc). The damage in Vancouver was centered around Stanley Park, primarily due to uprooted trees rather than flooding. This highlights the difference that tides and wind direction can make in the severity of flooding events in Vancouver, since the peak wind hours were outside of high tide ranges, and the westerly winds avoided more vulnerable areas.[16]

Image 6.3 (following page) *Photo A) Kitsalano Pool was swamped by waters that overtopped the retaining wall. Mike Klassen [Photo] 2012. Retrieved from http://www.vancouversun.com/Metro+Vancouver+storm+surge+climate+change+preview+expert+says+with+video/7709174/story.html. Photo B) Eroded foundations along the Stanley Park seawall caused sinkholes and other critical failures. Kim Stallknecht [Photo] 2012. Retrieved from http://www.vancouversun.com/Metro+Vancouver+storm+surge+climate+change+preview+expert+says+with+video/7709174/story.html. Photo C) Waves carrying debris battered the seawall, piers, and beaches along Stanley Park (pictured) and West Vancouver. Kim Stallknecht [Photo] 2012. Retrieved from http://www.vancouversun.com/Metro+Vancouver+storm+surge+climate+change+preview+expert+says+with+video/7709174/story.html. Photo D) The first floor of the Silk Purse art center in John Lawson Park was flooded by surge waters. Mark van Manen [Photo] 2012. Retrieved from http://www.vancouversun.com/Metro+Vancouver+storm+surge+climate+change+preview+expert+says+with+video/7709174/story.html*

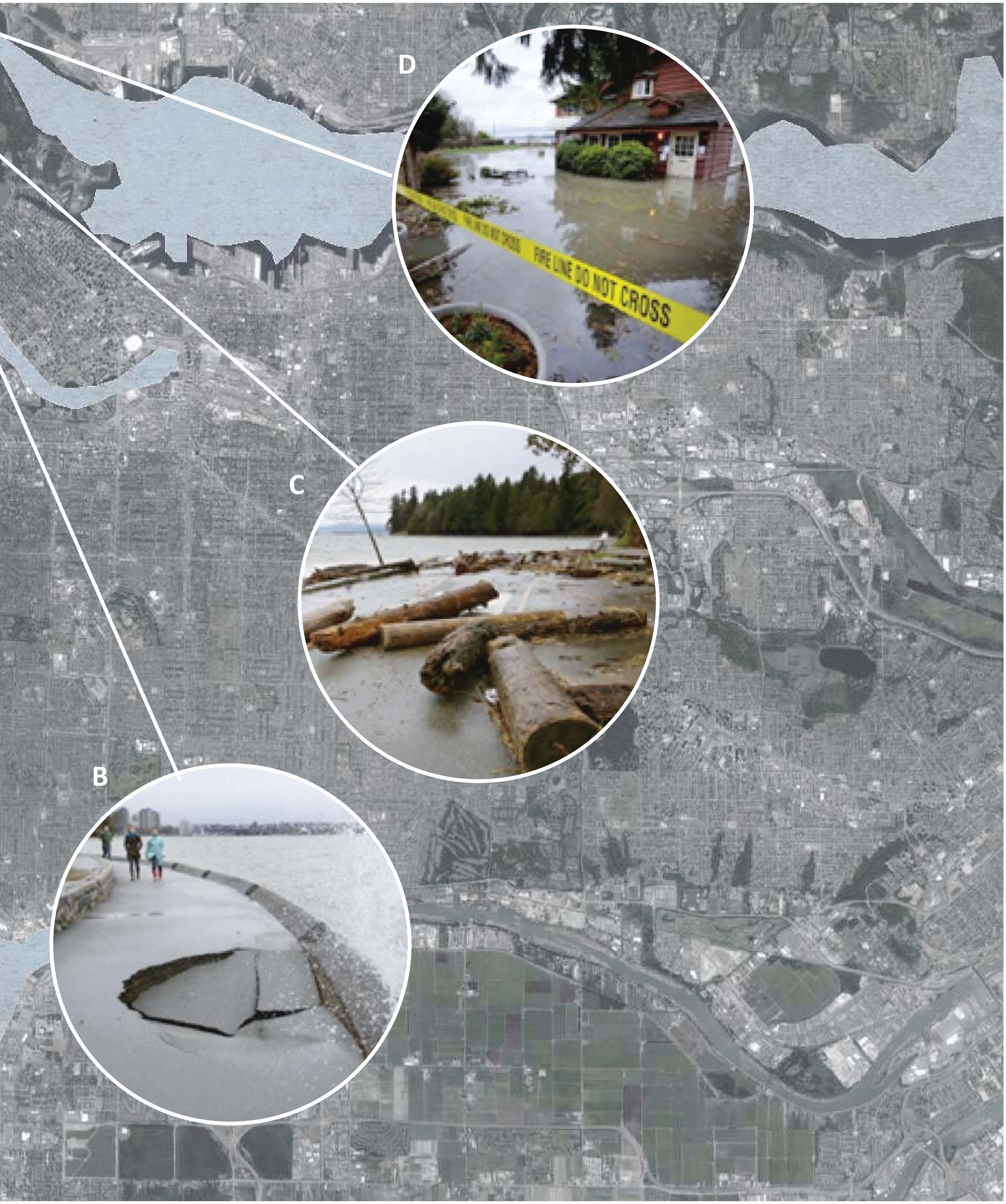
The King Tide Windstorm of December 17th 2012

The storm that tracked across Vancouver Island and the Strait of Juan de Fuca on December 17th 2012 was not an especially powerful windstorm, nor did it bring record levels of rain like the infamous Hanukkah day storm of 2006 did. What it did have however, was a pristine sense of timing. The storm coincided with the perigean spring tide (King Tide), with sea levels peaking around 5.5m high, a full meter over what the expected tide level would be. The additional surge, provided by the storm, in this case just 69cm, was all it took to produce sea levels high enough to flood and cause serious damage in coastal areas.



The storm that caused the flooding was one of several to pass through the Cascadia region in the month of December, but unlike the others, it alone had the requisite low pressure center (983mb) to produce relatively strong winds, with sustained speeds of up to 31 mph (50 kmh) in Vancouver and gusts of 40 mph (65 kmh)[17]. As the storm tailed off over Vancouver Island the winds rotated westerly, coinciding to the hour with the high tide and resulting in a storm surge that crested the seawall in several locations around the city.

Damage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Unlike the Hanukkah eve storm, with its heavy winds and rain, the characteristics of the storm of December 17th resulted in the damages being focused almost entirely along the coastline. Stanley Park and West Vancouver saw the brunt of the flooding, but there was damage all along the shoreline.

Waves crested the Stanley Park seawall in several places, breaking pavement and throwing logs and debris onto the pathways[18]. Recreational beaches were flooded, as were some municipal buildings near the coast. At Jericho Park, giant logs thrown by the storm surge damaged a wooden pier, putting it temporarily out of service, and Kitsilano Pool was completely inundated. West Vancouver also saw its seawall damaged with rocks and logs smashing into the retaining wall and jumping onto pathways.

Casualties

There were no direct casualties from the flooding, although several car crashes were reported in the area attributed to the storm, one of which was fatal.[19]

Analysis

This storm in particular was a good indication of what the next 100 years may bring for Vancouver in terms of climate change's effects on sea levels.[20] As sea levels rise worldwide, the storm surge levels reached by this rare convergence between storm and tide (a once in 50 years occurrence) will become more and more frequent, even without factoring in more volatile weather patterns.

Image 6.4 (following page) *Photo A) Paseo Wheelwright, a popular boardwalk overlooking Valparaiso Bay, suffered major damges to its wooden deck all along its length. Patricio Winckler. [Photo] 2015. Photo B) The temporary closure of Caleta Portales hurt local tourism and fishing industries that depend on the infrastructure there for their businesses. Soy Valparaiso. [Photo] 2015. Retrieved from http://www.soychile.cl/Valparaiso/Sociedad/2015/08/08/338969/Olas-de-hasta-5-metros-provocan-graves-danos-en-el-borde-costero-de-Valparaiso-y-Vina-del-Mar.aspx. Photo C) Massive waves crashing against sea defenses at Juan de Saavedra, between Caleta Portales and Curva de los Mayos. Agencia Uno. [Photo] 2015. Retrieved from http://www.theclinic.cl/2015/08/08/galeria-hd-la-intensa-marejada-que-azotoPhoto D) Waves completely covering Playa Acapulco in Viña del Mar. Agencia Uno. [Photo] 2015. Retrieved from http://www.theclinic.cl/2015/08/08/galeria-hd-la-intensa-marejada-que-azoto-la-v-region-en-imagenes/*

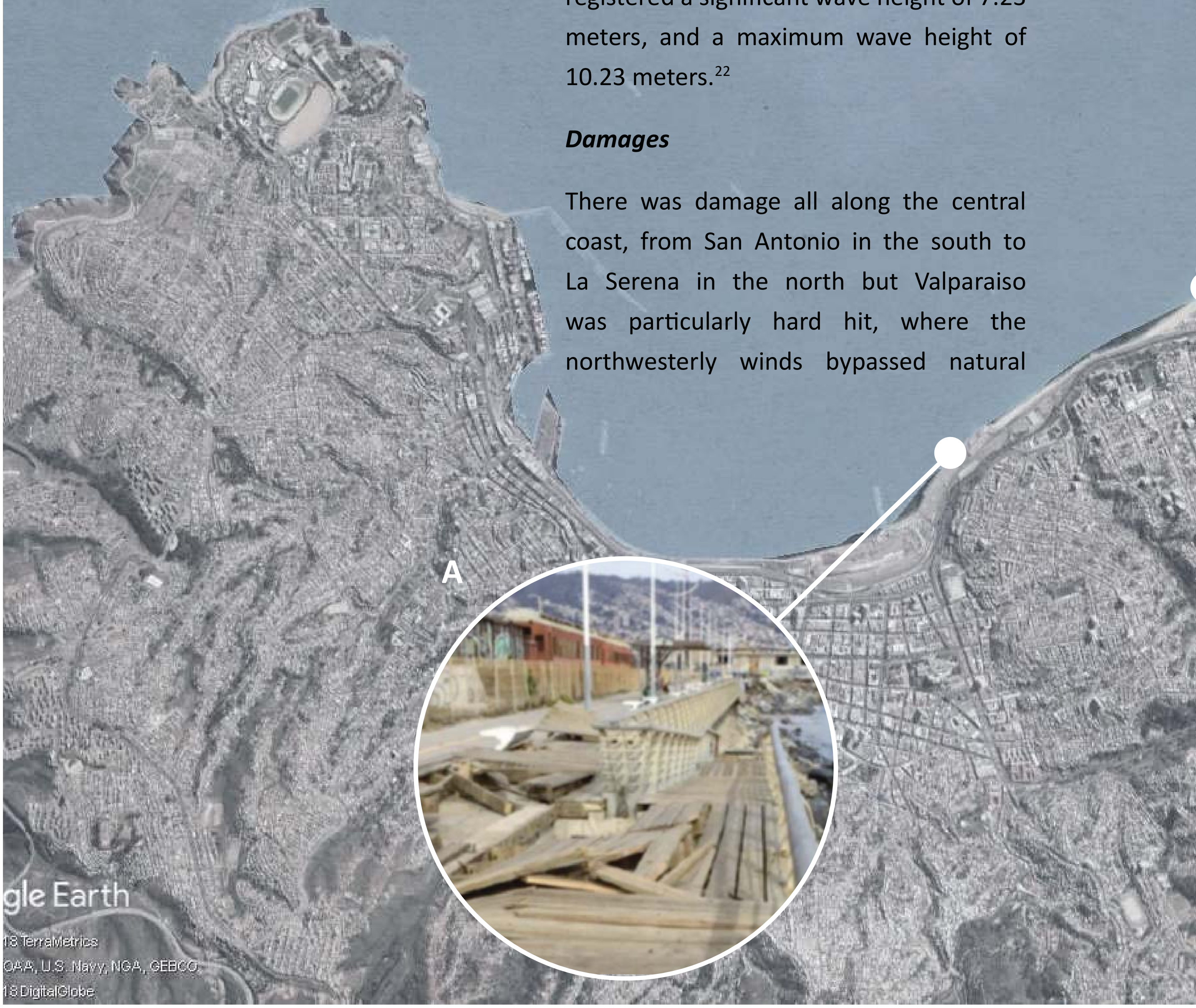
Gran Valparaíso-August 8 2015

On August 8th of 2015, a powerful storm struck the central coast of Chile, causing significant damage in coastal cities along a 500 kilometer stretch of coastline, from Coquimbo in the north to Bucalemu in the south. The storm is notable for the severe levels of storm surge it produced and the subsequent damage in coastal infrastructure.

Just one of several weather events that struck the Chilean coast over several weeks that August, the August 8th event stood out from the rest for its wind speeds, gusting up to 68.4 mph (110kmh) and low pressure, reaching 981mb as it moved off the coast of Valparaiso[21]. Data from a Watchkeeper buoy deployed by SHOA in Valparaiso bay registered a significant wave height of 7.23 meters, and a maximum wave height of 10.23 meters.[22]

Damages

There was damage all along the central coast, from San Antonio in the south to La Serena in the north but Valparaiso was particularly hard hit, where the northwesterly winds bypassed natural

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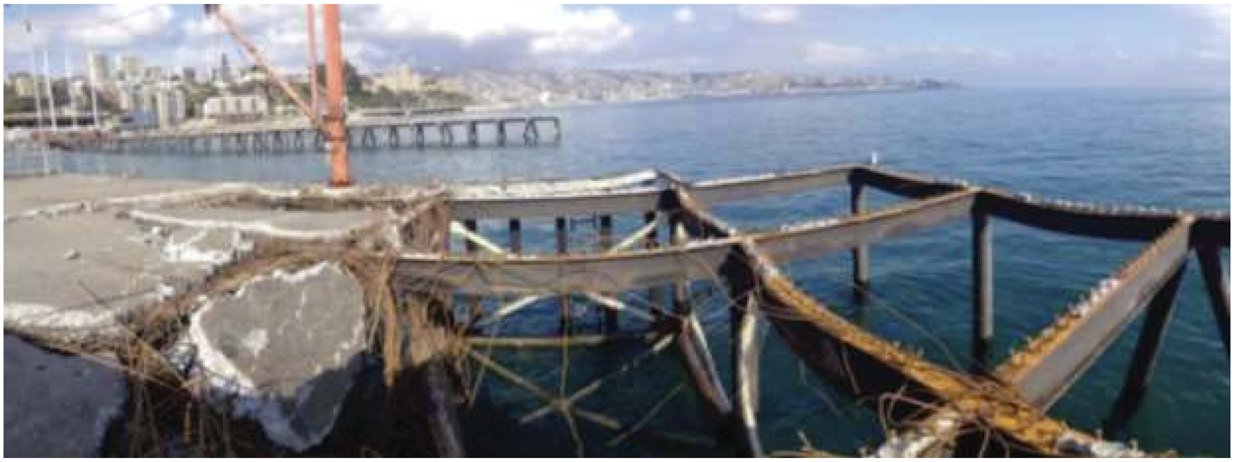

Image 6.4 *The extensive damage to the 'new pier' and the crane (pictured) at Caleta Portales meant local fishing boats were unable to embark. Patricio Winckler. [Photo] 2015.*

defenses like Point Angeles to strike hard at normally sheltered piers and coastline. Initial estimates from the port authority estimated over 5 billion dollars in damages to the coastal infrastructure in Gran Valparaiso.[23] In addition to the damage to public works, the ministry of the Interior and Public Security (ONEMI) registered 4,276 persons affected by the storm, including 533 private residences damaged.[24]

The stretch of coastline between the neighborhoods of Cerro Barrón in Valparaíso and Cerro Recreo in Viña del Mar was particularly vulnerable to the westerly winds. Paseo Wheelwright, a popular boardwalk for exercise or sightseeing, saw damage to its infrastructure estimated at $700,000 dollars.[25] The wooden walkway of the boardwalk was seriously damaged, as were various lighting elements and urban furniture. Coastal erosion was also a major issue in this event, as the beach along paseo wheelwright had over 35,000 cubic meters of sand and particulate moved from the zone.[26]

Caleta Portales, an active fishing pier and popular lunch spot for tourists and locals alike, sustained $1.6 million dollars in damage to both its pier (inaugurated in 2005) and its main building, which houses both merchant stands and restaurants. The pier was especially damaged, as repeated pounding from waves caused five of the concrete slabs that formed the pavement of the pier to completely separate from their frames and a further two were irreparably damaged.

Several buildings along the coastline near the promontory of Cuerva de Los Mayos, just past paseo Juan de Saavedra, suffered heavy damage as well, including two belonging to the Chilean Navy. The combination of wave action and eroded foundations, especially on reclaimed land, caused upwards of $1.15 million dollars in damages to four buildings.

The Recreo Yacht Club, even with a sheltered harbor area, had a boat sink and suffered damages to its pool and main clubhouse area. Additionally, beach erosion from farther down the coast brought particulate to the dockage area, lowering the total draught with new sand.

Several prominent tourist areas in Viña del Mar were also affected, such as the Sheraton Hotel, whose entire basement floor was flooded. Waves passing over the seawall at Avenida Peru led to flooding in streets and apartment buildings up to several hundred meters inland, and caused serious damage to several restaurants situated on the popular tourist avenue. The beaches of Viña del Mar also saw massive amounts of erosion, as an estimated 31000 cubic meters of sand moved at Playa Caleta Abarca exposed the concrete foundations of the old pier. Playa Acapulco, just off Avenida Peru also experienced erosion heavy enough to critically damage its wooden boardwalk.

Casualties

In the central coast, the storm took one life, an architect who died trying to save his sinking boat in Concón. Outside of Gran Valparaíso, the event claimed another five lives.

Analysis

This was the most damaging event in recent history for Gran Valparaíso. Strong winds combined with a more westerly wind direction caused damages beyond what was normal for this type of winter storm (*temporal*). Studies suggest that these types of storms with uniquely high wave heights, called meteotsunamis, will become more common with the changing climate.[27] If that is the case, these types of damages could become the norm rather than the exception. The highly visible damage to popular areas and the prominent press coverage can be seen as a direct contributor to the subsequent study carried out by the Chilean National Hydraulic Institute regarding the adaptation of Avenida Perú and Juan de Saavedra.

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VII-ADAPTATION RESPONSES

Plans and Reports-Vancouver

In December of 2014 the City of Vancouver Coastal Risk Flood Assessment (CFRA) Phase 1 was published by Northwest Hydraulic Consultants, a local engineering firm specializing in water resources. The report details in over 140 pages the threats the municipality of Vancouver faces from rising sea levels and extreme weather events. A year later Phase 2 of the same assessment was published, examining possible solutions and strategies for the vulnerable areas outlined in phase 1. At 250 combined pages, the CFRA is a comprehensive look at how a coastal city can prepare for the dynamic threats they will increasingly be facing in the coming century. Before we examine the CFRA and its implications however, it’s important to understand the adaptation planning in the city of Vancouver that preceded it, and how those plans laid the groundwork for the policies of today.

Clouds of Change - 1990

Vancouver became the first city on the American continent, and one of the first worldwide, to attempt to comprehensively tackle the issue of climate change with their 1990 report Clouds of Change. This report examined the global threat of climate change (at that time referred to as *atmospheric change*) and how it would affect Vancouver. It proposed 35 actions for the city that would begin to mitigate the production of damaging gasses by the city. It was, for its time, an ambitious document, recognizing the need to take corrective locally action before critical points were reached globally. The introduction lays out the reasoning plainly, well before most of the world had begun to consider, much less accept this type of thinking: “*Atmospheric change means* we *have to change.”*[1]

Many of the goals set out in Clouds of Change are more directed towards influencing behavioral changes of citizens and businesses, such as minimizing uses of plastic packaging or encouraging the practices of telecommuting or working from home, although there is a section dedicated to land-use changes for the city to consider. [2] The report raised awareness throughout the region about the necessity of behavior altering decisions, but despite its ambitious goals, not much came from the actual recommendations. As one of the key participants put it 22 years later:

But in fact, we made very little differ-

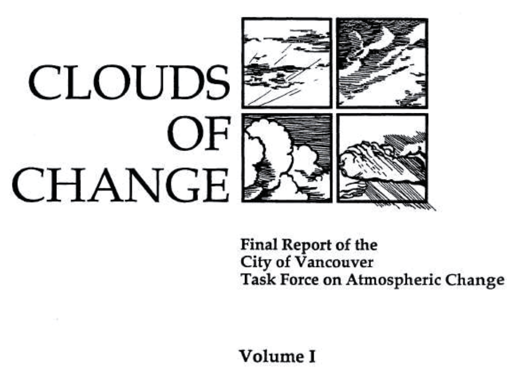


Image 7.1 *The Clouds of Change report was Vancouver's first foray into climate adaptation planning. Source: City of Vancouver Planning Department. [Image] 1990.*

ence. Our predictions as to the levels of CO2 and impacts were derided as being wildly imaginative; we turned out to be conservative. Virtually every one of the 35 recommendations got glowing acceptance comments from the powers that be, but little was implemented.[3]

Perhaps the most consequential of the recommendations were the very last three, through which we can see the development of a culture of adaptive planning.

- Recommendation 33: *Study Adaptive Measures* directs the city to study and produce reports on "measures required to adapt to local consequences of atmospheric change, such as sea-level rise…"[4]

- Recommendation 34: *The City's Role* promotes the role of the municipal government in the adaptation process, including the goal of supporting citizens and government officials in specific projects in response to climate change in cooperation with other parts of the world. Specifically the city could provide guidance "by developing policies and technologies which will be in high demand elsewhere in the country and the world".[5]

- Recommendation 35: *Public Involvement and Education* suggests that fostering public awareness of both the threats the city faces and the campaign to address them will "develop public support for local initiatives [to address climate change]"[6]

Recommendations numbers 33, 34 and 35 began to lay the groundwork for the future planning and preparation the municipality would see in the next 25 years. This 'groundwork' specifically has similarities to the principles of resilience thinking, notably their concepts of 'encouraging learning' and 'broadening participation. Regarding the principle of participation, the Stockholm Resilience Center tells us that:

> Involving a diversity of stakeholders in the management of social-ecological systems can help build resilience by improving legitimacy, expanding the depth and diversity of knowledge, and helping detect and interprest perturbtions…It may occur in various –or all- stages of a management process, although diverse participation can be particularly useful in the startup phase.[7]

These recommendations in particular can be seen as focusing on creating the environment necessary for applying future adaptations. As we covered previously in a social-ecological system, adaptation to changing environments is not a given when factoring in the actions (or inactions) of humans actors. Adaptability must be developed, and the Clouds of Change moved Vancouver towards that end.

Greenest City 2020 Action Plan (GCAP) - 2011

While the Clouds of Change report may not have generated the type of traction in the city government as its authors had envisioned, it did provide a blueprint to interested parties in Vancouver of how to develop a more enduring and impactful solution: The Greenest City Action Plan (GCAP). Formalized in 2011, this plan sets out ten goals for the municipality to become what they call the 'greenest city in the world' by the year 2020. Goals range from the more open

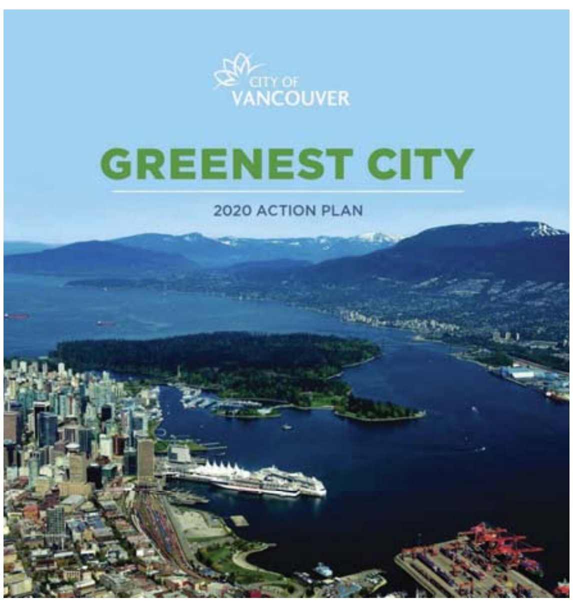


Image 7.2 *The Greenest City 2020 Action Plan is a comprehensive look at adapting the social-ecological system of Vancouver as a whole to the changing environment. Source: City of Vancouver. [Image] 2011.*

ended (increase amount of locally grown food consumed in the city) to the very specific (decrease CO2 emissions in existing buildings by 20%). Some of the goals were clearly evolutions of recommendations originally from the Clouds of Change report. For example, the 1990 document called for the city to

> *…make bicycling a better transportation alternative by providing ample bicycle parking and related bicycle facilities; implementing and expanding the Vancouver Bicycle Plan; and improving enforcement of all traffic laws relating to road sharing by bicyclists and motorists."*[8]

The Greenest City Action Plan built on that, mandating that the city aim for half of all trips in its borders be by foot, bicycle, or public transportation. This, incidentally, is one of the goals that Vancouver has already reached: in 2015 the city announced that it had achieved its goal of having the majority of trips be by some mode other than automobile.

It wasn't only the goals of the 1990 plan that provided outlines for the GCAP, but the process of researching and enacting the plan as well. The Greenest City process started in 2009 with an external panel that compiled information about leading cities worldwide in each category of climate adaptation that Vancouver wanted to address. The next step involved a buy-in from the entire city government, as separate city departments took ownership of each of the 10 goal areas, all of them working underneath a temporary Greenest City office formed specifically to help integrate and guide the planning process. Approaching the process via a model of polycentricism allows for greater resilience across the entire system as well, since no one department can collapse the entire system if they fail.

The experience with the first climate change plan showed planners that they would need broad public support to move their goals beyond "glowing acceptance comments" to actual implementation. As such, from the very start they sought to involve various social groups, diversifying the stakeholders in the enterprise and tying the community closer to the future of the plan. As part of the process the city started a public-facing initiative called *Talk Green To Us* to interface with the public at large. Through presentations to civic groups and an online campaign that reached out to the public across social media platforms, *Talk Green To Us* solicited input from citizens on how the city could meet its ambitious goals. According to city estimates, over 35,000 people contributed in some form or another to the planning process.[9] This emphasizes the focus on building resilience through participation, not only engaging the public in an ambitious project, but potentially unearthing unknown information that would otherwise have been overlooked.

Climate Change Adaptation Strategy

Although a Climate Adaptation Working Group had existed in Vancouver since 2007, it wasn't until the push for adaptability was featured as a quick start option of the Greenest City plan that a wide-ranging climate adaptation strategy became a reality. The city joined the Local Governments for Sustainability (ICLEI) Climate Change Adaptation Initiative pilot in 2010, and working through their methodology created the Greenest City Climate Change Adaptation Strategy. With its formal adoption in 2012, Vancouver became the first municipality in British Columbia with a climate adaptation plan.

The Climate Change Adaptation Strategy is a comprehensive report examining the risk and vulnerability of city infrastructure and citizens to four principal climate change effects[10]:

1. Increase in intensity and frequency of heavy rain events
2. Sea level rise
3. Increased frequency and intensity of storms and weather extremes
4. Hotter, drier summers with more heat waves

For each of the categories, primary and supporting actions are identified that would not necessarily solve the issues presented, but rather put the city in a better position to respond to them. As the report itself notes:

> *The strategy is a living document and will continue to be revised and updated as climate change science and adaptation practice evolves. As this is the first Adaptation Strategy for Vancouver, many of the proposed actions focus on increasing our understanding of coming challenges and integrating climate change into planning, design and emergency management. Successive iterations of the Strategy will yield more detailed actions.* [11]

Noting that although observable effects from rising sea level may take some time to appear, due to complicated environmental and financial implications involved in adaptation projects, there is a sense of urgency to begin discussing options. To that end, the first primary action recommended in the sea level rise section is for a Coastal Flood Risk Assessment to determine the best mitigation options for city infrastructure.

Coastal Flood Risk Assessment (CFRA) Phase 1 and 2, 2014-2015

The CFRA was carried out by an external team of consultants in two phases. Phase one was a detailed look at the threats posed by sea level rise and flooding, as 5 potential climate change and storm scenarios were modelled for their impacts on various regions of the city. Phase two summarizes the potential management solutions to the vulnerabilities outlined in phase one. Possibilities discussed cover all three adaptation strategies, and a future third phase will focus on specific recommendations from phase two with feasibility studies and other planning activities.

The phase one actions identified significant anticipated impacts to public infrastructure and homes in Vancouver, suggesting a 1/500 year storm event *today* would cause 1700 displaced households and nearly 500 damaged buildings. Projecting that same storm with a 1 meter sea level rise would cause 4000 displaced homes and more than 800 damaged buildings. Additional noted potential impacts included economic disruption, environmental degradation from floodwaters mixing with contaminants, and social trauma.

Phase two took the findings of the phase one report and applied them to eleven distinct zones of the city. Going zone by zone, the report:

1. Examines the potential flooding scenarios and the assets affected for each zone

2. Presents a series of potential adaptation strategies, including pros and cons posited by external stakeholders

3. Reviews the consequences and

Protect 60% of propsed strategies	• Sea Barrier • Sea Wall • Dike (road or inland) • Structured Wall • Cliff Armoring
Adapt 26% of proposed strategies	• Zoning changes restricting critical infrastructure and buildings in floodplains • Elevating city infrastructure • Building code changes to flood proof new and existing buildings • Development of flood warning systems
Retreat 13% of proposed strategies	• City buyouts of property, followed by removal of roads and infrastructure and eventual re-naturalization of area.

Table 7.1 *Overview of the distribution of CFRA Phase II adaptation strategies presented in final report.*

tradeoffs associated with adopting or declining each potential alternative

The adaptation strategies presented are classified into the three categories we covered previously: protect, adapt, or retreat. Table 7.1 shows the frequency with which each category of strategy was deemed appropriate by the authors of the study, as well as the most common implementations proposed.

While the report does detail zone specific mitigation strategies, the key takeaway from the CFRA is the proposal for a Coastal Flood Adaptive Management Plan that would work to guide the municipality's decision making around adaption strategies going forward. The proposed Adaptive Management Plan would provide a framework for both evaluating the feasibility of zone specific actions, and more crucially, *when* to implement them. Projecting the effects of sea level rise on coastal flooding is a long-term exercise, and making decisions now for problems of the future is, at best, spending resources unnecessarily, and at worst, locking the city into solutions that may be irrelevant or undesirable in future scenarios.

The adaptive plan imagined by the CFRA report would function on a 5 year update cycle in order to maintain flexibility. Every five years the city would review the status of their existing mitigation efforts, as well as the new developments in climate science and the local implications. From there, they could make decisions about what actions, if any, to take within that next five year window. This allows for changing variables to inform their decisions, such as:

-new climate science

-new vulnerabilities in the city

-effectiveness of previous mitigation actions

-changing values of citizenry

The majority of the infrastructure adaptations discussed above would take serious investments of time and resources, meaning a time buffer is needed between when a risk becomes too great and when the mitigation effort to assay that risk is put into place. The CFRA suggests an automatic trigger system that would allow sufficient time to plan, develop, and implement strategies deemed necessary. In this case, the trigger would either be a set level of sea level rise (i.e. 60cm) or a fixed number of critical buildings and infrastructure at risk (i.e. 10% of buildings at risk during a 1/500 year storm). This suggestion is a way of formalizing the adaption leg of the resilience circle we previously examined, bypassing the inherent unreliability of human actors in order to force adaptation processes every five years.

Code Adaptations-Vancouver

A review of the relevant laws governing construction in Vancouver show that the municipality uses its position as the only municipality in British Columbia with the power to enact its own building codes in order to impose stricter rules than stipulated by provincial law on buildings and infrastructure in the city. Among its city-specific laws are the Flood Plain Standards. Passed in September of 2014 as a direct result of the CFRA phase one findings, the new flood plain standards are an example of a mitigation strategy to adapt current infrastructure and buildings to potential hazards. The purpose of the bylaws are to provide special zoning regulations to buildings built within the floodplain, that is, within an area of the city deemed susceptible to flooding. New construction within those specific areas are subject to a special Flood Construction Level (incorporating sea level rise to the year 2100 and a 1:500 year storm) as well as permitting restrictions that seek to protect both the homeowner and the city from damages.

Per the Vancouver Building By-law No. 10908, the Flood Construction Level states that the underside of a floor system or the top of a concrete slab in a habitable build-

Zone	Site Coverage	Floor Area Ratio
RS-1	40%	0.6
RT-2	45% (Senior housing 40% including exterior paths)	0.6 or 0.75 depending on height
C-1	Not Applicable	1.2 or .75 for dwelling units
M-2	Not applicable	5.0 for manufacturing, tranportation and storage 1.0 for all other uses

Table 7.2 *Site coverage and Floor Area Ratio demands for principal zoning areas along waterfront in City of Vancouver.*

Image 7.3 *A) Map of designated floodplains for Metro Vancouver based on flood risk asessment to 2100, including sea level rise, in CFRA Phase I. B) Example of building elevated using pile foundations in Maine coastline, USA. Photo by P.A. Slovinsky 12-2009.*

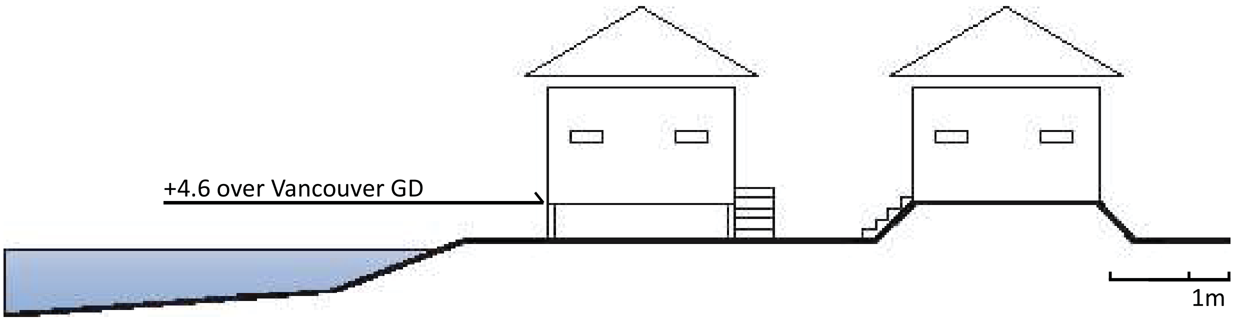


Image 7.4 *Diagram of possible elevation solutions according to Vancouver Floodplain Standards from 2014.*

ing, must be 4.6 meters above the Vancouver datum point.[12] This can be achieved either by raising the grade of the site or elevating the base of the structure. The FCL by-law does not make any changes to pre-defined zoning regulations in regards to site coverage (*ocupación de suelo*) or floor area ratio (*coeficiente de constructibilidad*). The vast majority of the zones within 100 meters of the shoreline in Vancouver are zoned as RS-1, a single family residential district. The only other residential zone that appears with any frequency close to the shoreline is RT-2, a 2 family district that allows for some multifamily housing. C-1, a commercial/residential zone, is the second most common within 100 meters of the shoreline, especially in the False Creek Flats area and downtown. Finally, the port and its immediate surroundings are zoned M-2, an industrial and manufacturing district. Table 8.2 summarizes the common shoreline abutting zoning types and their site coverage and floor area ratio requirements.

Subdivision requirements in the bylaws include legal covenants that acknowledge the danger of flooding in the area and an engineer's report positively affirming that the land is suitable for its intended purpose.

Plans and Reports-Valparaíso

Valparaiso, and Chile in general, has a much shorter list of experiences to draw upon for its adaptation planning projects. As part of its continuing involvement in the United Nations Framework Convention on Climate Change (UNFCCC), Chile developed a national plan to confront the issues they will face nationally from effects of climate change. The *Plan de Accion Nacional de Cambio Climatico 2017-2022* (PANCC) examines the threats global climate change poses to Chilean communities and critical sectors of the economy, specifically noting the danger to infrastructure posed by:

> *…an increase in the intensity and frequency of storm surges, putting at risk coastal populations, damaging not only the coastal infrastructure, but also the environmental services and associated economic activities,*

affecting ports, piers and beaches.[13]

First and foremost the PANCC is a guidepost for ministries and municipalities when approaching adaptation issues. It is less focused on dictating specific goals or solutions than it is on collecting information and developing the context necessary for climate adaption strategies to take place. Action paths are identified in four main categories (Adaptation, Mitigation, Means of Implementation, Climate Change Management at the communal and regional level) with discrete goals in each. In terms of storm surge, this means better understanding the risks and vulnerabilities of Chilean communities, specifically through a report every two years (starting in 2018) that details each coastal inundation event, and starting in 2020, detailed inundation and risk maps as well. Additional reports, also as part of the Adaptation action path, are called for to cover the various sectors of the Chilean economy and environment.

Understanding the environment and hazards present is a crucial part of being able to appropriately adapt a system and increase its resilience. The fact that as of the publish date of this investigation neither map nor report exists suggests there is a deficiency in the capacity of the system to appropriate adapt itself after a disturbance. This may be a case in which the human actors are hindering rather than helping the adaptability of the coastal border system.

For the infrastructure of the country, this resulted in the *Plan de Adaptación y Mitigación de los Servicios de Infraestructura al Cambio Climático 2017-2022*. Following the pattern of the more comprehensive PANCC, this offers plans of action regarding adaptation and mitigation options, this time specifically focused on a range of public infrastructure across the country. The plan does not detail specific measures, but does highlight the urgent need in Chile for better observation and analysis programs to provide a better base for understanding the impacts of potential adaptation strategies and properly evaluating best options.

On the local level there has been some movement towards adapting the coastal border, particularly after the storm of August 8, 2015. The massive failure of the coastal defense infrastructure during that event put on display the potential for serious damages to life and property during extreme weather events.[14] As a result, in 2016 the *Direccion de Obras Portuarias*, a subset of the Ministry of Public Works (*Ministerio de Obras Publicas, MOP)* tasked with oversight of all water related infrastructure and architecture, commissioned a study "*Analisis Para el Estudio de Mejoramiento de Defensas Costeras en los Sectores de Avenida Peru y Juan de Saavedra*" with the aim of improving the mitigation capabilities of two especially hard hit areas along the Gran Valparaiso coastline.

Stages 1 and 2, completed in 2016 and 2017 involved review of previous studies and study of the wave patterns, respectively. Stage 3 focuses on Avenida Perú, modelling and testing in a wave machine the current state of the coastal defenses along the length of the popular, as well as four alternative proposals that would potentially offer higher levels of protection. In the initial stage 3 report, released in February 2017, three situations are modelled of varying storm intensity and tide levels to gauge the levels of overtopping and of damage to the defense system itself. The maximum storm level considered was a 100 year return period while the maximum tide was +2.68m. In July of the same year a further study was released analyzing an option involving an artificial beach added to the existing rocks.


Instituto Nacional de Hidráulica
Ministerio de Obras Públicas
Gobierno de Chile

Dirección de Obras Portuarias
Ministerio de Obras Públicas
Gobierno de Chile

DIRECCIÓN DE OBRAS PORTUARIAS
MINISTERIO DE OBRAS PÚBLICAS

"DISEÑO CONSERVACIÓN DEFENSAS COSTERAS
SECTORES AVENIDA PERÚ Y JUAN DE SAAVEDRA"

INFORME ETAPA 1: RECOPILACIÓN, REVISIÓN Y ANÁLISIS DE ANTECEDENTES, Y TRABAJOS DE TERRENO (TOPOBATIMETRÍA)

PEÑAFLOR, REGIÓN METROPOLITANA
Octubre 2016

Image 7.5 *Study of design options for improving resilience to storm surge in Viña del Mar and Valparaíso. Source: DOP. [Image] 2016.*

The July report concludes by recommending the initial construction of the so-called 'optimized alternative', essentially an additional layer of tetrapods placed after the existing rocks, similar to what exists currently at Juan de Saavedra. After a period of observation an additional expansion of the current concrete wall could be undertaken, effectively changing to proposal three, which according to the modelling would reduce overtopping by up to 74% compared to the current defense.

Three additional measures are recommended regarding dealing with the overtopped water once it passes into Avenida Perú:

-concrete planters fixed to the pavement on the opposite sidewalk to break the energy of overpassed water

-improving the drainage system

-closing the street to vehicular and pedestrian traffic during extreme weather events

Stage 4 of the study is currently underway examining coastal mitigation options for Juan de Saavedra.

This study and the proposed changes to Avenida Perú represent an effort to increase the resilience of the Viña del Mar waterfront to storm surge by adapting the existing protection coastal defense. The study is detailed in its summary of previous projects and its modelling of wave actions along the rocks and retaining wall. As we covered in the Case Studies section, the impetus for this project was the damaged suffered during the August 8th, 2015 storm, and all available evidence shows an effort to learn from what failed in previous iterations in order to improve the functioning of the coastal system. But it is unclear what exactly the lessons learned are. Rather than an evolution of ideas to adapt or transform the waterfront system and its defenses, none of the solutions tested stray beyond the realm of elongated or raising the defenses that currently exist.

Code Adaptations-Valparaíso

The Instrumentos de Planificación Territorial for Valparaiso are mostly silent on the issue of storm surge and coastal inundation. Zoning by-laws for each municipality give site coverage and floor area ratios for buildings within them, though there are no specific coastal border zones which demand mitigation or adaptation measures. The zoning areas that border the waterfront for the municipality of Valparaíso are given in table 7.3. Of note are the use restrictions that maintain a paradigm designed around the port and industry, as well as the setbacks from other buildings. Combined with restrictions on the length of the buildings, this does prevent clumped buildings that would fare poorly during a tsunami. In the context of the use restrictions and the massive lot sizes (compared to V6a for example), it's much more likely these by-laws are related to keeping the waterfront free for commercial and industrial exploitation that they are for mitigating risk.

The Plan Regulador Comunal de Viña del Mar defines the coastal border (*borde costero, BC)* thusly:

Zone	**Principal Use**	**Site Coverage**	**Minimum Lot**	**Distance between buildings**
A1	Port -Industrial-Railway	10%	10,000m2	30m
A2	Artisanal Commerical Fishing	10%	5,000m2	100m
A3	Port-Industrial-Railway	50%	10,000m2	30m
G	Recreational	20%	n/a	10m
V6a	Residential	<9m=50% >9m=30%	500m2	3m

Table 7.3 *Zoning comparisons for main zoning areas in Valpraíso (A1, A2, A3, G) and Viña del Mar (V6a) that border the waterfront in areas affected by storm surge.*

> *It is the zone between the streets that run along the coastal edge and the sea, which extends from the limit with the comuna of Concón until the southern limit of the Comuna of Viña del Mar with Valparaíso at El Sauce. This zone is comprised of the beach areas as well as the rocky areas that abut the ocean and provides space for a large number of persons for recreational and touristic ends.*[15]

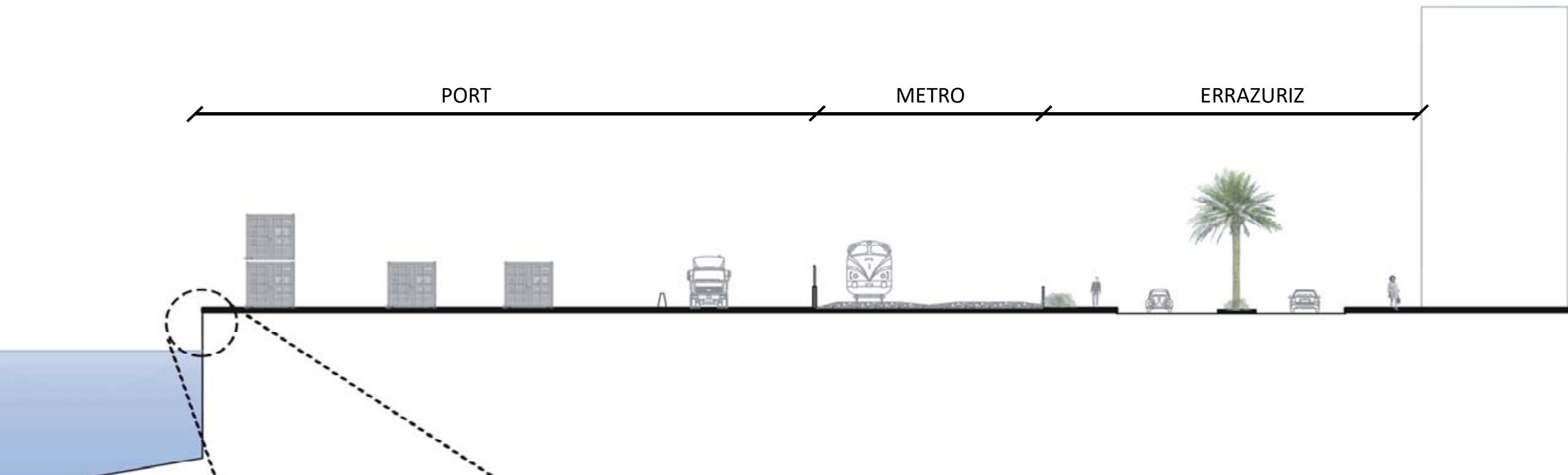
As we noted previously, it was not until the early-to-mid 1900´s that the coastal border of Viña del Mar was began its conversion from industrial to recreational use. Part of this was achieved through law no. 13.364, commonly known as Ley Lorca, which, by declaring the buildings along the coastal border to have a public utility, managed to give some measure of control over the type of buildings constructed.

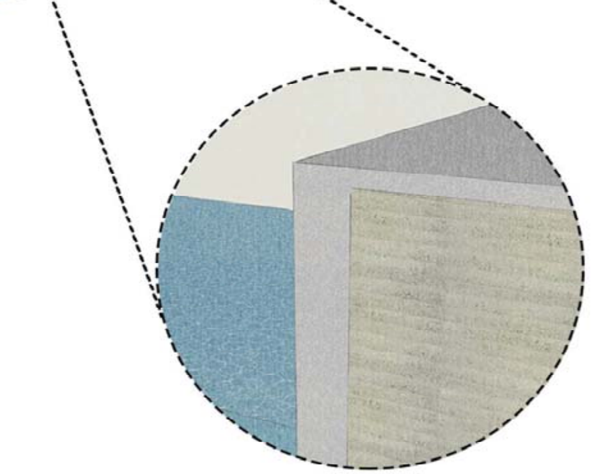
Nor are there specific construction guidelines for buildings in flood or (tsunami) planes, as there are for anti-seismic construction. Those codes, based on similar laws in the United States, are developed and published by the National Standards Institute (Instituto Nacional de Normalización). Examined and revised after each major seismic event in the country (1985, 2010, etc.), these standards not only play a large role in the identity of Chilean construction, but are internationally recognized as successfully saving lives.[16]


N
COASTAL DEFENSE
SURVEY LOCATIONS
VALPARAÍSO
Juan de Saavedra
Paseo Wheelwright
Avenida Errazuriz

Avenida Errazuriz

Large thoroughfare in Valparaíso, running parallel to the coastal border. Thanks to port and city metro holdings, there is a large offset between coastal border and public access for almost the entirety of Valparaiso's coastline





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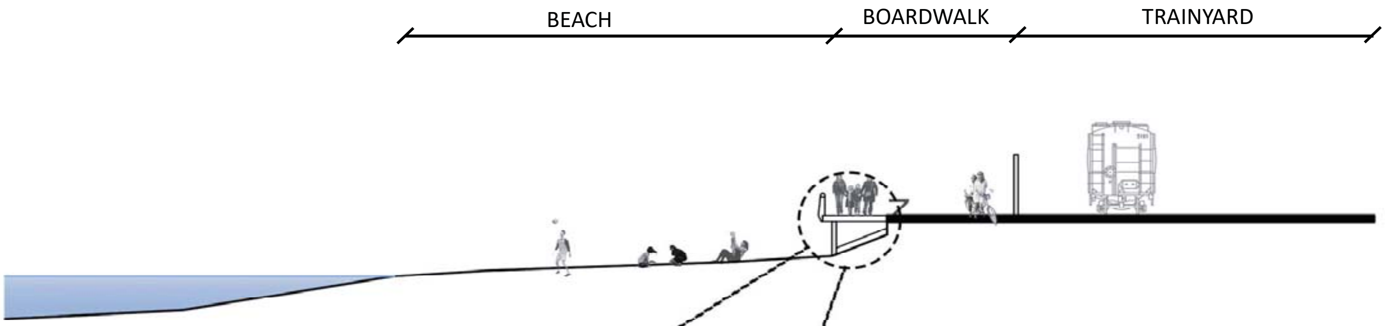
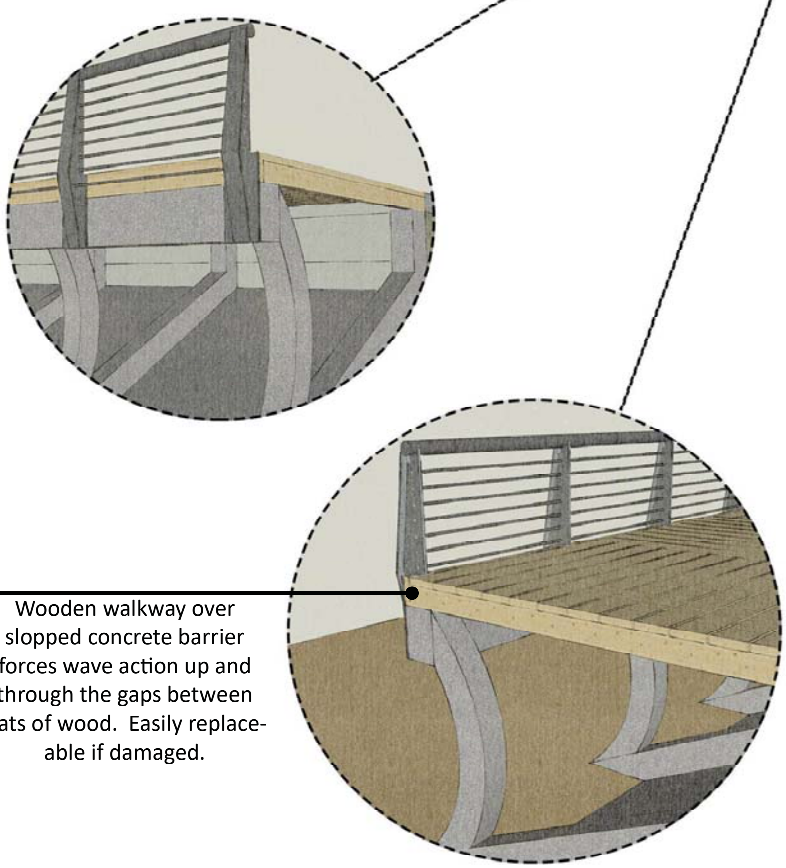
2

Hard Defenses:
-concrete barrier raising city elevation several meters above sea level
-concrete wall aprox 1.5m in height dividing port holdings from metro
Soft Defenses:
-very large setback from public access to border

Paseo Wheelwright

Popular boardwalk stretching from Muelle Baron to Caleta Portales, offering access to beaches with occasional points of recreation or relaxation. Consolidated into areas of passage and areas of 'being', with lookouts that lean out into the ocean.





Wooden walkway over slopped concrete barrier forces wave action up and through the gaps between slats of wood. Easily replaceable if damaged.

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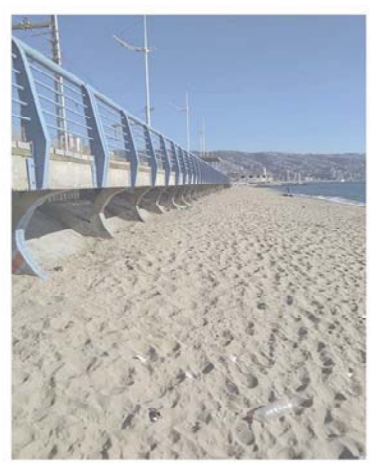
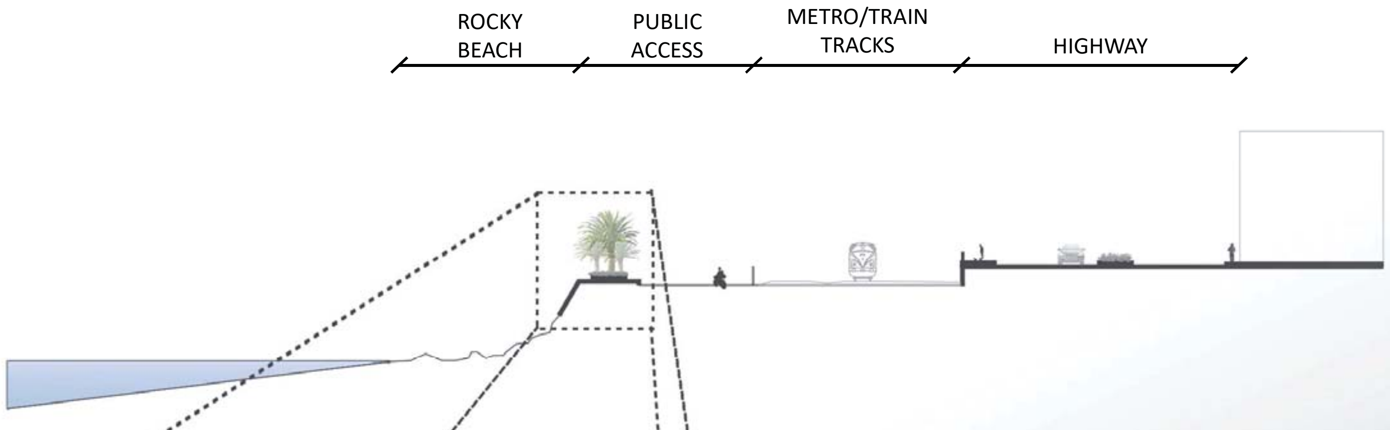
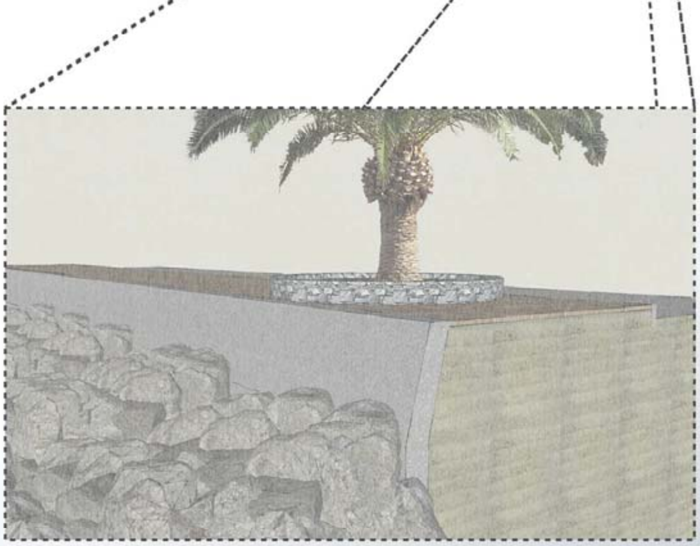
2



Paseo Juan de Saavedra

Mostly abandoned area just north of the popular Caleta Portales in Valparaíso. Deteriorated contention walls and stone pathways are all that remains in an underutilized space. Currently only a passageway between the main highway (Avenida España) and the naval buildings at Curva de Mayos.





The concrete retaining wall is fronted by a rocky beach and topped by large stone planters, usually containing small palms. Much of defense has eroded away under wave pressure and combined with its underuse, today gives off the appearance of a ruin.

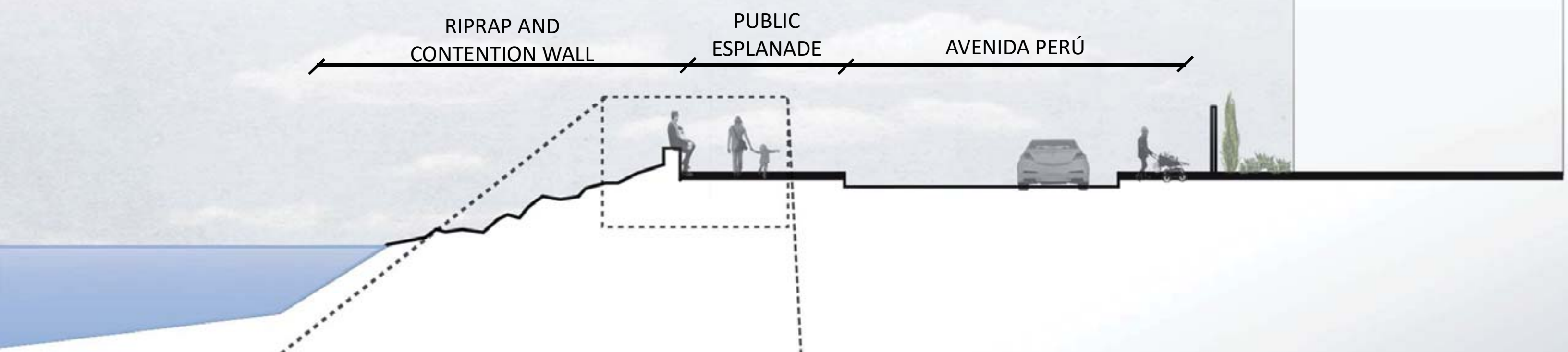
1

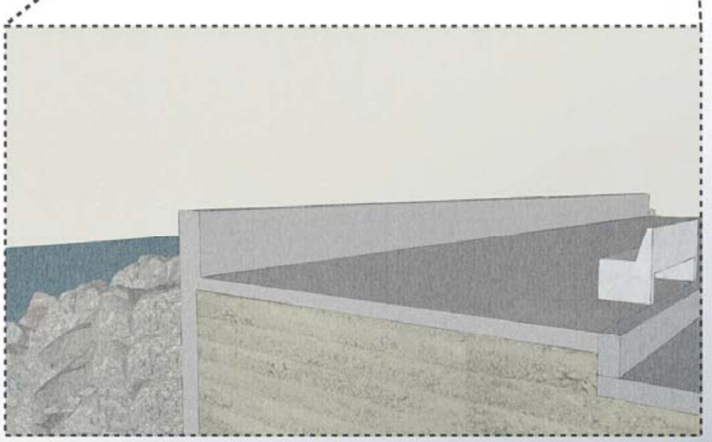
2


N
Coastal Defense
Survey Location
Viña del Mar
Avenida Perú

Avenida Perú

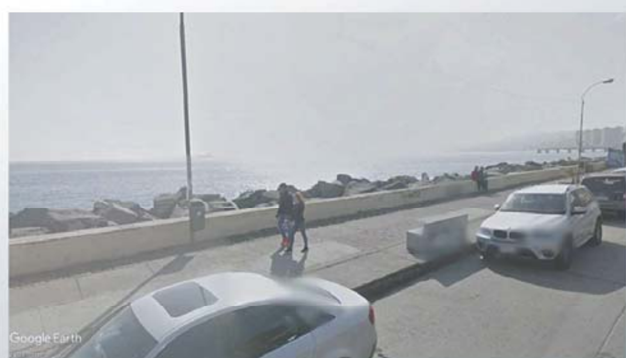
Wide explanade in Viña del Mar very popular with tourists and locals alike, offering priveleged views of Valparaíso Bay. Primarily a pedestrian throughway although there are residences opposite the border.





The inclined riprap wall and raised concrete barrier have proved insufficient to stop overtopping from powerful waves, most notably during the storm of August 8, 2015.

1



2

Despite partial adaptations to overtopping storm surge in buildings along Avenida Perú, including inclosed ground floor patios, many residences still suffer damage during extreme weather events.

Endnotes

1 City of Vancouver Planning Department. "Clouds of Change: Final Report of the City of Vancouver Taskforce on Atmospheric Change." June 1990. P.

2 Idem.

3 Price, Gordon. "Clouds of Change Report Online-with thoughts from a venture capitalist" Price Tags. January 25, 2013. https://pricetags.ca/2013/01/25/clouds-of-change-report-online-with-thoughts-from-a-venture-capitalist/. Accessed May 5, 2018

4 CVPD. "Clouds of Change" 1990

5 Idem

6 Idem

7 Sturle Hauge Simonsen. Applying Resilience Thinking: Seven Principles for Building Resilience in Social-Ecological Systems. Stockholm Resilience Centre, 2015.

8 Idem

9 City of Vancouver, 2011 (July 5), Administrative Report from Deputy City Manager to Vancouver City Council re: Greenest City 2020 Action Plan. Available online: http://vancouver.ca/files/cov/GCAP- council-report.pdf

10 City of Vancouver. "Greenest City 2020 Climate Adaptation Strategy". Vancouver, BC. 2012

11 Idem

12 City of Vancouver Building By-law Number 10908, Flood Construction Levels and Regulations related to Designated Flood Plains (September 2014)

13 División de Cambio Climático del Ministerio del Medio Ambiente, Gobierno de Chile. "Plan de Acción Nacional de Cambio Climático 2017-2022".

14 Winkler, et al. "El temoral del 8 de agosto de 2015 en la región de Valparaíso, Chile Central". Latin American Journal of Aquatic Research, 45(2) 2017

15 La Ilustre Municipalidad de Viña del Mar. "Plan Regulador Comunal de Viña del Mar". 2002. p.6

16 Sanchez, Ray. "Experts: Strict Building Codes Saved Lives in Power Chilean Earthquake". CNN. April 3, 2014. https://edition.cnn.com/2014/04/02/world/americas/chile-earthquake/index.html. Accessed May 31, 2018.

VIII-DISCUSSION

The scientific community has comfortably aligned behind the idea that climate change will have dramatic implications for human settlements worldwide. Evidence from our comparisons suggest that coastal cities in particular will need to reevaluate not only their coastal defense systems, but the urban planning paradigms that have guided their decision making processes up to this point.

Minimizing disruptions from climate change effects as measured by casualties and insurance costs will clearly be a priority for all cities, but the economic and cultural profiles of coastal cities like Vancouver and Valparaiso suggest complications that stretch beyond the readily quantifiable. The very identity of coastal metropolitan areas are so inherently tied to the ocean that any change in that relationship can be extremely difficult to process.

Cultural evidence from civilizations on every continent suggest a historically complicated relationship between man and ocean, playing the role both of provider and destroyer of livelihoods. That connection has always been complex, but we seem to be entering into a new era of the relationship between man and environment. Some scientists suggest that evidence exists that the planet is transitioning from the Holocene epoch, which it has been in since the end of the last ice age almost 12,000 years ago, into the Anthropocene epoch, one defined by human impact on the planet.[1] Never in the millions of years of planetary history has a species influenced the earth the way the human species has begun to influence the stability of our environment.

As we come to grasp with that fact and as our understanding of the world around us continues to evolve, this paradigm has become less and less valid. We are seeing ourselves and our cities as just one part of nested systems; no longer the sole protagonists, we are instead part of an ensemble cast.

<u>Hypothesis 1</u>: Over the next 100 years,

Image 8.1 *Evidence abounds of the historic connections to the sea in both Vancouver and Valparaíso. The crests for each city (the city of Vancouvers to the left, the Valpraíso regions to the right) reflect the importance of the relationship with the ocean, each contrasting an image of a sailing ship with land based images. Vancouvers motto "By Sea and Land we Prosper" could easily be placed under Valparaísos crest and retain the same meaning.*

changes to storm surge levels produced by extreme weather events will require coastal cities to change the paradigms that guide the development and design of the coastal border.

This hypothesis rests on two assumptions explored through the methodology of the thesis:

1. Coastal cities of the Americas face unique challenges from changes both internal and external.
2. The urban design paradigms that shaped our cities of today are not adequate to respond to the challenges of the future.

Challenges facing coastal cities

The unique internal challenges that the American coastal cities will have to contend with over the next 100 years are centered on the demographic changes they will undergo, and the often outsize role they play in the livelihood of their regions.

The demographic changes involved mainly revolve around the increasing demand for, and ever present lack of, space. Similar tectonic histories have assured that the presence of the American Cordillera and other coastal mountain ranges in the west coast of the Americas will always present problems for cities seeking to expand their presence on the land. Cities have adapted to the physical restrictions in a number of ways (increasing density, reclaiming land,

Image 8.2 *View of the 'Malecón' in Valparaíso, the street border of the city and sea, during a storm in 1900. The street was protected by a metal structure made of vertical railroad ties embedded in the sand every 15 to 35 centimeters, filled in-between with granite. Source: Harry Olds. [Photo]*

etc), but given the natural barriers, there is always going to be a tension between city and environment. This tension is inflamed by the demographic changes taking place worldwide, as the steady urbanization of the world population continues to increase the need for space in cities worldwide.

Beyond the inherent physical limitations of their settlements, there are other considerations that make American coastal cities particularly vulnerable to the effects of climate change. For one, any disruption to their system can have massive ripple effects for the wider area. As we covered in our contextual comparison, the port and tourism industries are critical not just to the metropolitan area of Gran Valparaiso, but the entire region. Cruise ships that dock in Valparaiso feed tourists to wineries in Casablanca, boutique hotels in Santiago, even ski resorts in the Andes. Likewise, companies from all over Chile depend on the port of Valparaiso to export their goods to the rest of the world: more than 30% of all foreign trade to Chile comes through the port of Valparaiso.[2] The beaches of Gran Valparaíso, especially in the municipality of Viña del Mar, are major tourist attractions on their own right, the product of a conscious effort by city officials in the mid-to-early 20th century to position Viña del Mar as a tourist destination. Although its industrial past can still be seen in spots along the coastline (most notably at the recently remodeled Muelle Vergara), zoning and other by-laws designated the coastal area as recreation-specific.

Vancouver likewise is the point of entry into the entire western half of Canada, serving as the backbone of a tourism industry that contributes more to the GDP of the provincial economy than any primary resource industry outside of oil and gas[3]. Its port is the jumping off point for cruises going north towards Alaska and millions of tourist a year come for the natural setting of British Columbia itself.

For both Valparaiso's Zona Central and Vancouver's Cascadia, it can be said that a widely disproportionate amount of the regional economy, culture, and in many ways, identity, is tied to a relatively tiny stretch of land of their principal city. Regardless of other benefits or drawbacks, this puts an enormous responsibility on the design of the border in these metropolitan areas, to ensure the entire region is not unduly affected by damages at such a small percentage of its land area.

Externally, the coastal cities of the Americas will face the brunt of the most impactful changes brought by climate change. While the types of threats both cities face are similar, both in terms of natural hazards and in terms of climate change scenarios, they differ in degree and some particulars. Settled on the shores of a sheltered body of water and protected by a series of islands

Image 8.3 *Vergara Pier (Muelle Vergara) in Viña del Mar, before its recent remodelling. Built in 1894 its location in the middle of the most popular beach in the city serves as a reminder how systems can transform themselves. Source: Marítimo Portuario. [Photo] 2015. Retrieved from http://www.maritimoportuario.cl/mp/comenzo-el-retiro-de-emblematica-grua-del-muelle-vergara-en-vina-del-mar/*

Image 8.4 *The newly remodeled Muelle Vergara. Source: Municipalidad de Viña del Mar. [Photo] 2016. Retrieved from http://www.soychile.cl/Valparaiso/Sociedad/2016/12/15/435651/Vinamarios-podran-visitar-el-muelle-Vergara-hasta-las-23-horas-durante-el-verano.aspx*

from the open ocean, Vancouver does not face the same level of danger from hazards like tsunamis or meteotsunamis that Valparaiso does. Its location does however mean it its more impacted by projected changes to sea level, as the king tides, today minor concerns, would result in major flooding events with an extra meter of sea level. Combined with the extremely wet climate of the Cascadia region, whose precipitation levels are also projected to increase as a result of the changing climate, Vancouver's infrastructure is particularly susceptible to overloading and flooding.

There exists a level of urgency for Valparaíso projects that does not necessarily correlate to Vancouver. The threat Vancouver faces from climate change is more immediate, but as we see from historical case studies and analysis of the scientific community's outlook, it is a more predictable one. The strong correlation between damaging flooding events in Vancouver and local King Tides[4], allows for some level of predictability in forecasting how and when major flooding events will begin to affect critical city infrastructure and private property. Valparaíso's threat is both more, and less urgent than that of Vancouver. Tides have little correlation with flooding events in Valparaiso, instead the overall power of the weather event is a much stronger predictor of damages. Sea level rise in Valparaiso is much less of an immediate concern as well, as sources actually have sea levels in the region falling slightly in recent years. The highly variable rate of subsidence and uplift along the coastline however mean that that sea levels don't have the same long term predictability as they do in Vancouver.

Antiquated design paradigms

Both Vancouver and Valparaíso were settled in a time when our fundamental understanding of the world around us, and the ocean in particular, was much different. The ocean was tempestuous and unpredictable assuredly, but always something to be tamed and conquered by man. Though initially settled by Europeans in the early 16th century, Valparaíso grew to prominence as a city around the same time as Vancouver was being settled in the early to mid 1800's. The story of that era was one of expansion and exploitation across many scales. New inventions and advancements from the century before had opened the door to new paradigms of human interaction with their environment:

> *'The industrial revolution was the first spectacular triumph of the human species over the patterned ancient limitations of the natural world.' After thousands of years humans were no longer asking how to protect themselves from nature, but rather how to extend their dominance over nature to ensure eco-*

nomic progress.[5]

No better example of this sentiment exists than the process of land reclamation, or land fill, by which new land is created from that of the sea. At differing points in their history, Vancouver and Valparaiso found themselves lacking in buildable land near the city centers, and their response, like that of coastal cities worldwide, was to take the needed land from the sea. The process of land reclamation is an extremely common tactic in coastal cities, where buildable land in desirable areas is often half that of a similar landlocked city. Reclamation has one clear benefit (providing more buildable land) and a host of drawbacks, not least among them is that extending the coast into the oceans only exacerbates the eventual effects of sea level rise.

In Vancouver, the inlet known as False Creek used to be twice its current size before its flatlands were claimed by the city, and the popular shopping area Granville Island was little more than a sandbar before it was built up. For its part, the coastline of the municipality of Valparaiso has undergone at least 5 distinct expansions since 1835, to the point where today nearly all of the most critical functions of the city take place on in-filled land. In Viña del Mar, Avenida Perú, the area most affected by storm surge damages, is built over what used to be beach front.

Surveys of the coastal zones in both cities studies show a coastline that has encroached ever further into the ocean, and coastal borders designed around consolidating for human exploitation the land claimed from the sea. Local zoning regulations, in Valparaíso especially, support this idea, as they dedicate large swathes of waterfront to industrial or transportation function via use restrictions. The current coastal defenses, as well as those being considered for the near future, are almost exclusively protection strategies, specifically those designed around increasing short-term engineering resilience. During a disturbance, their primary goal is to return the system to its pre-disturbance state as quickly as possible. As suggested by Holling, et al. in their 1996 paper comparing engineering resilience to ecological resilience, this focus on bounce-back ability may be reducing the capacity for those same systems to adapt themselves to a changing environment.

The old relationship between man and sea was based on the understanding of the ocean as a constant presence, with knowable hazards and a reasonably static coastline. In this system, humans were the sole protagonists, and any changes were products of our changing values, norms and technologies (i.e. coastal protection zones vs. coastal development). Ever evolving value systems have begun to call into question some of the cultural foundations of

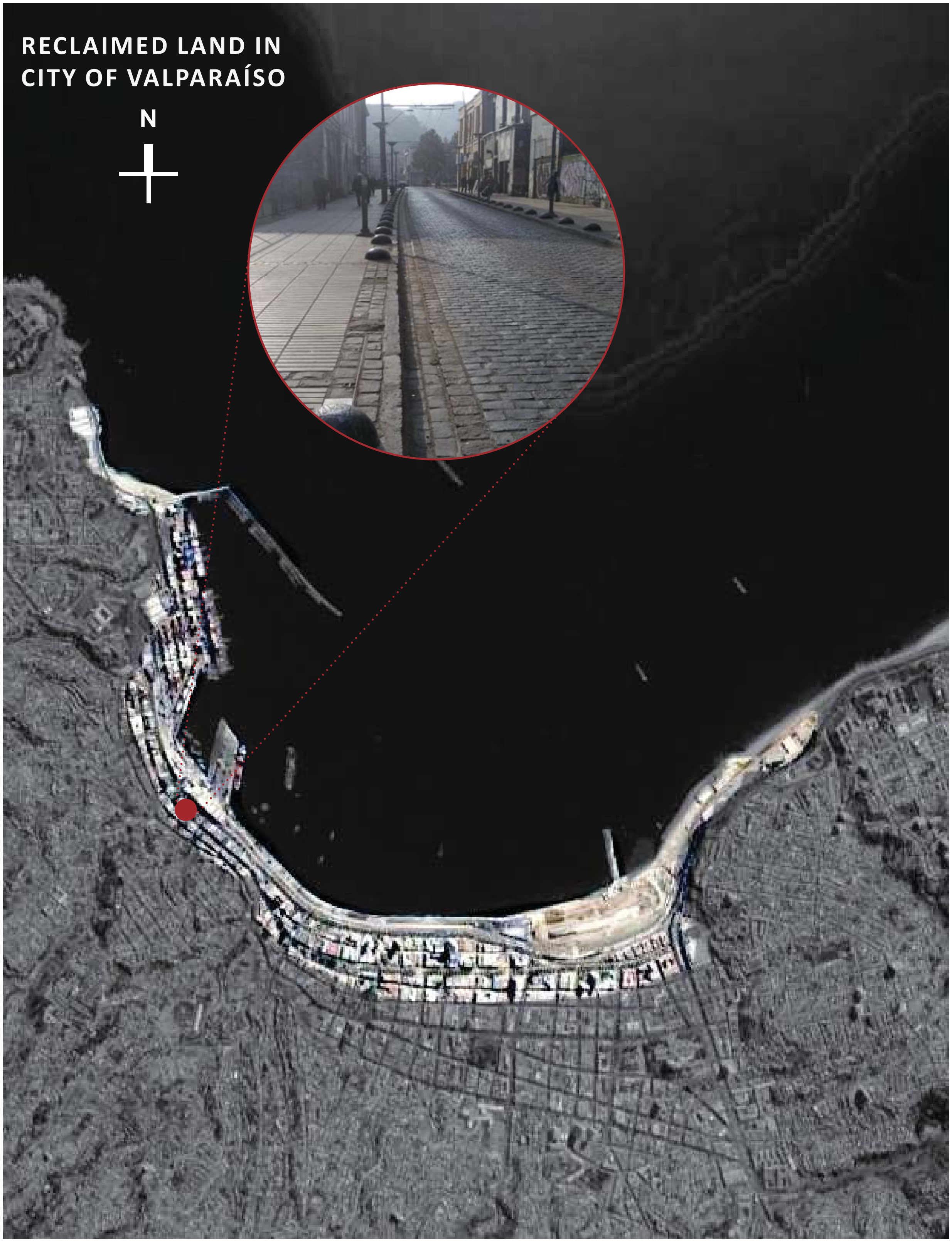


Image 8.5 *This line of red paving stones on Serrano Street in the port district of Valparaíso marks the 1818 city border with the sea. Photograph taken by author.*

that relationship though, and recently even some of the evidence based assumptions we have made about the environment that undergirded that paradigm are proving less reliable than previously thought.

The last decades have seen both Cascadia and the Zona Central of Chile begin to re-examine their understanding the ocean-based hazards to which they are exposed. Evidence recently uncovered of past mega-earthquakes that occurred off the coast of the Pacific Northwest have reshaped the concepts of the threats posed by tsunamis. Unlike a country like Japan, which has a well recorded and preserved history of its various earthquakes and tsunamis over a millennium, the written history of the Pacific Northwest extends only back to European colonization in the mid 1800's. As historians and scientists in the region explore the oral history of indigenous peoples and evidence left behind in the geologic record, a new vision emerges of the potential hazards the ocean harbors.

Similarly, Valparaiso is recently beginning to come to terms with its own history of tsunamis. Official planning documents and SHOA inundation maps suggest that Valparaiso is reasonably safe from tsunamis: literally the only mention of tsunami in the *Plan Desarrollo Comunal* de Valparaiso is on page 26, where it mentions that Valparaiso does not have a history of catastrophic tsunamis.[6] This conclusion is roundly contradicted by a new study which relies on historical recreations of the 1730 earthquake in Chile to estimate inundation levels that are far above the current maximum levels in SHOA's inundation maps.[7] Even more recently, the Regional Ministry of Housing and Urbanism (*Ministerio de Vivienda y Urbanismo*) for the fifth region indicated that it intends to carry out a study of the tsunami risks in its coastal areas in order to update its zoning regulations.

These cases highlight how changes to our built environment take place as part of a process, one that begins with a changing understanding of the world around us. Adaptations to infrastructure and urban planning, before they are put into place in the physical world, require paradigm shifts that allow us to view the ocean, and the environment more broadly, as a dynamic entity. This step is crucial, because the ultimate goal is not simply to adapt the infrastructure for climate change, but rather to create and sustain built environments that are themselves adaptable.

Hypothesis 2**: *Vancouver's experiences in climate adaptation can provide helpful examples for Valparaiso to follow as it begins the process of exploring coastal flooding mitigation options.***

Climate change adaptation will be a costly, if essential, investment for cities around the world over the next 100 years. As we covered, it is the coastal borders in cities in particular that will face massive challenges from the double force of rising sea levels and ever-increasing vulnerable populations, and will be a necessary focus of both financial and political investment for cities as they adapt their coastlines to rising sea levels and more frequent and powerful extreme weather events. Understanding the impact and risks associated with the changing climate is the first step in this process, one that has become more or less equally accepted worldwide. Deciding how and when to spend the economic and political capital that will be necessary for adaptive strategies in coastal zones is the next step, and here some cities have clearly outpaced others.

The City of Vancouver, while yet to enforce any serious infrastructure changes along its waterfront, has conducted studies of the threats and proposed a system to guide their decision making into the future. Valparaiso is now starting the same process, and experiences in Vancouver can help shape the form of the discussion going forward. Our exploration of the differences between the two cities' approaches thus far have yielded three main takeaways in which Valparaíso can learn from the experiences of Vancouver.

These are the three main takeaways from Vancouver's experience that can be applied to Valparaiso:

- Increasing resilience in the coastal border requires meaningful citizen engagement.

- Coastal resilience requires a system wide effort, both politically and culturally, built towards emphasizing and fostering the capacity to learn and adapt to ever changing environments.

- Adaptation strategies are applicable in almost all environments, and offer ways to use to the existing environmental (built, natural, and cultural) advantages to the benefit of the city.

Increasing resilience through citizen engagement

Vancouver's experiences with its several climate adaptations plans highlight how integral citizen involvement is in order to effectively carry out the eventual conclusions. The first efforts at climate adaptation were ambitious, as embodied in the Clouds of Change report, but lacked the popular support to carry out the majority of the ideas presented. Later versions focused on building citizen engagement as a central part of the efforts. Talk Green to Us, the public-facing component of the 2011 Greenest City Action Plan, is a useful example of how community engagement can be deployed in service of an adaptation plan. Thanks in part to the public outreach efforts, Vancouver has had much more sustained success with its implementation of resilience building through its Greenest City Action Plan, making improvements over their baseline measurements in every single category they explored.[8]

Applying something like this to Valparaiso could take a number of forms. The culture and history of Gran Valparaiso are linked closely to the sea, but a large part of the current citizenry is less and less connected to the border itself thanks to private development or transportation infrastructure dedicated to automobiles. This separation may contribute to the lack of public awareness of how changes to the environment will likely affect the city. Changing land use patterns to provide more access could help encourage public involvement in future planning.

Implementation of a government sponsored program like *Talk Green to Us* to inform and seek input from the public, with events located at coastal border sites like Juan de Saavedra or Avenida Peru could contextualize the challenges facing the city.

Valparaiso, like Vancouver, is home to a number of renowned universities that have historically been drivers of social change, providing opportunities for government-university partnerships to future explore ideas and solutions relating to resiliency in coastal areas. The city of Vancouver for example paired with the local Simon Fraser University to sponsor the 'The Octopus' Garden', a series of talks hosted by the university in summer and fall of 2017 centered around how cities, Vancouver in particular, can manage the challenges posed by sea level rise. A similar outreach program in Valparaiso could involve universities such as Pontificia Universidad Catolica de Valparaiso, Universidad de Valparaiso, and Universidad Tecnica Federico Santa Maria, and would not only offer new outlets of investigation, but would provide a new generation of young people engaged with the issues facing the region.

The plan set forth in the CFRA approaches the predictability by establishing a 5 year review cycle to periodically re-evaluate interim changes in environment, policy and culture. One of the key points made by the CFRA, and one very much relevant to Valparaíso, is the importance of continuously evaluating the cultural context of the situation. Solutions that may be considered anathema today may be acceptable, or even desirable 25 years from now.

Although re-evaluation and analysis is a critical part of adaptation plan, one as focused on long term change such as Vancouver is working towards would still leave Valparaiso vulnerable to more immediate, less predictable events. Slow, measured change is appropriate in a region where damaging flood events are tied closely to rising sea levels, but in Valparaiso the flooding events are violent and unpredictable, much less . Adapting the coastline in Gran Valparaiso demands a different approach, one that incorporates periodic analysis, but that focuses more on immediate action to create flexible, adaptable spaces and leans on the community to develop resilient systems.

Building resilience across the panarchy

The paradigm guiding social-ecological system thinking tells us that cities, being large SES's themselves, are made up of many individual systems, nested and interconnected between each other. Within the SES, the concept of panarchy suggests the distinct systems that compose the greater social ecological system are all constantly acting upon each other. The coastal zone of a city may well be a unique system, but its impacts reach deep into the metropolitan area, and the region that surrounds it. Building resilience is not something that can be undertaken in isolation, rather, it must be approached holistically with the understanding that building resilience at the border also means building resilience in the systems that interact with it.

The concepts of resilience thinking reinforce this idea: among their discussion of practical applications they highlight the importance of managing connectivity, noting that highly interconnected systems can provide benefits to the social ecological system as a whole, but may also facilitate the spreading of the impacts of a disturbance in an isolated area.[9] Human systems face an additional layer of complexity in that we must consider the social aspects of having highly integrated or segregated networks. Social groups can share information and cultural ideals across network boundaries, potentially bringing new perspectives and norms to more conservative constituencies, paving the way for adaptations outside the realm of current political consideration. As with other ecological systems though, social connectivity also comes with a price, in that it can lead to the homogenization of ideas:

> *Studies show that when homogenisation of norms occurs, the explorative ability of social actors drops, leading to a situation where the network members all think in the same way and may believe they are doing well while they are actually heading towards unsustainable pathways.*[10]

The suggested lesson here is that while connectivity is important to the overall resilience of a city, it needs to be carefully managed. Vancouver's Greenest City 2020 Action Plan is an example of what it looks like to attempt to build resiliency into the entire social-ecological system. The focus Vancouver has put into improving the resilience of their coastal border in the face of sea level rise is just one part of a massive effort at reshaping the entire city around the wide ranging effects of climate change.

The program includes serious infrastructure and urban planning changes, such as the extension of the public transit sky train, expansion of their public park system, or changing building codes to emphasize energy efficiency. Sharing equal billing with these programs are others, designed not so much to effect the built environment, but rather the behavior of those who interact with it. These include projects designed to encourage local food consumption (through the expansion of number of local farmers and community markets) and platforms that engages and educates local businesses to encourage them to lower their environmental footprint.[11] Strategies such as these may not directly influence the coastal border but they do play a role increasing its resilience. Because of the relationship between each nested system in the large social-ecological system, increasing resilience in one can obliquely increase it in others.

One example touched on previously, of which both Vancouver and Valparaíso exposure, would be improving the functioning of storm runoff systems. Similar to the discussion of land reclamation from the sea, at various points in their histories the need for habitable land led to both cities paving over or constraining natural streams and runoffs that would otherwise carry the excess water to the ocean or help mitigate the rise in local sea levels. The delta of the estuary Marga Marga in the municipality of Viña del Mar is a prime example of this situation: during major storm events heavy precipitation works in conjunction with the increased local sea levels to overload drainage systems and exacerbate flooding at the coastal border. Improving functionality of the carrying and drainage capacity of the estuary, while not directly an intervention in the border, would nonetheless serve to increase its resilience capacity.

Perhaps as importantly as the physical adaptations in connected systems can have on the border area are the influences such changes can have on what we would normally consider within the realm of possibility.

Emphasis on adaptation strategies

If there is only one lesson that can be extracted from Vancouver's experiences with climate change adaptation, it is undoubtedly this: it is a truly massive undertaking. Decades of study and planning went into every change, and even then, actual results produced can be minimal. While the understanding that climate change will require serious changes to city systems is growing (in Europe around 80% of cities over 500,000 residents have a mitigation or adaptation plan in place)[12], there remain serious hurdles to action that limit the breadth and width of solutions possible at this time. Speaking during a city council meeting in 2016 for example, Mayor Gregor Roberston of Vancouver told the council that "From my perspective it's hard to imagine a managed retreat given the value of land and the scarcity of land we have here".

Given the very real restrictions that exist on possible strategies, for the most immediate impact, it is the category of adaptation strategies that offer the most plausible route for building resilience in coastal areas. For Valparaíso these solutions come in two forms: near term or long term.

Near-term adaptations

In the short term Valparaíso must contend with coastal infrastructure suited neither for the types of storm surge they are currently experiencing, nor for the other hazards that threaten the coast. Locations like Avenida Peru in Viña del Mar and Juan de Saavedra in Valparaíso face the brunt of the damages today, but with changes to storm direction, could bring the same force onto other more sheltered areas in Valparaíso. Immediate answers to address this situation are available if we consider the border through its ecological resilience lens and take into account the *latitude* inherent in the coastal border system: it can withstand occasional flooding and stay functional within its basin of attraction if designed to do so.

As Vancouver's experience has shown, territorial planning instruments (Instrumentos de Planificación Territorial, IPT) offer a number of ways in which to adapt the border area. Among the most direct and obvious tools would be to create a specific zoning area for the strip of land most effected by storm surge. This would allow the city to:

-Set a Flood Construction Level, requiring new construction to have its base floor slab be elevated to a specific height, reducing risk of flood damage during storms. Vancouver´s specific flood construction level of +4.6 meters was based on the CFRA Phase 1 modelling results for the region, and any FCL in Valparaíso or Viña del Mar should be as well.

- Adjusting site coverage and floor-area ratios to encourage favorable distributions of habitable floor space above ground floor and away from potential flood damage.

-Restrict the use of buildings constructed along the border, limiting ground floors to commercial and storage uses. This would greatly diminish physical danger to residents and personal property damage.

-Stop placement of critical infrastructure or services for vulnerable populations within the floodplain. This is a crucial point for hospitals and nursing homes in particular, as we noted previously the elderly popula-

Image 8.6 *Adapting current buildings, like this café on Avenida Perú in Viña del Mar, to be more resilient to climate change could mean raising their primary seating area to a second floor, rather than employ temporary measures like the plywood barriers shown. Photograph taken by author.*

tion in cities is projected to increase greatly by 2050 in search of healthcare in particular.

This last adaptation also underscores the necessity of an integrated approach as we touched on in the previous point. While removing vulnerable populations from potential inundation areas (either for storm surge or tsunami) is an important goal, the realities of the topography in Valparaíso and Viña del Mar mean that there is not much available land suitable for these types of services. Removing them from the floodplain likely means building in the hills or farther away from the center of the city, introducing problems in terms of accessibility for low mobility populations. This relationship between areas of the city highlights the nature of the panarchy: improving transportation and accessibility options for one sector of the city (hills) can end up effecting resilience in another (coastal border).

Another potential adaption is to the design and construction philosophies behind the buildings along the border themselves. These adaptations are not necessarily associated with planning instruments, though some, like using water resistant materials or flood proof construction concepts could be specified. Others are oriented around a design concept that seeks to accommodate the occasional floodwaters. Examples abound in flood prone areas worldwide, but an excellent example exists in Vancouver at Kitsalano Beach (Image 8.8).

Adaptations strategies are based around taking something existing and reinforcing its ability to respond to specific threats. To that end, existing soft defense programs, like the tsunami warning system already in place, could be used for warning residents in affected areas of potential surge events. The blanket alarm that occurs during a tsunami threat may be extreme for storm surge warnings, but repurposing the system to send text messages instead would be an effective way to adapt an existing system to a new reality.

Long Term Adaptations

The strategies we covered in the previous section are all things that could be implemented in Valparaíso within the next 5 to 10 years, and would serve as a base for the city to gradually increase its resilience to all manner of threats. Longer term solutions for the same purpose are more difficult to project, mainly due to the potential situational changes, as covered in Vancouver's CFRA Phase II report where they lay out some of the main issues with producing long term strategic sea level rise planning. The most important among them are the uncertainties in climate change projections,

Image 8.7 *Enforcing a flood construction level in Viña del Mar could prevent situations such as this on Avenida Perú. Photograph by author.*

Image 8.8 *The Boathouse restaurant at Kitsalano Beach in Vancouver is raised on columns, and has open space on the first floor that lets water pass through if flooding occurs. Source: Google Earth.*

the changes to the city itself, and the changes to the value systems which define what solutions are politically and socially viable. These ambiguities highlight the need for a system which can monitor and periodically reassess threats and solutions. The report on storm surge risk and vulnerability called for in the PANCC is a start, but it remains to be seen how effective it will be.

It is also possible that planners need to start thinking now about long term solutions that involve increasing not just the adaptability of the coastal border, but its transformability as well. Depending on how grave the effects of climate change end up being, it may be necessary for the border system to rearrange itself around new variables. This would move the focus onto developing the *social-ecological* resilience of the coastal region. Resilience in this sense, which we previously explored as resilience thinking, recognizes that there may be more than one acceptable stable state for the coastal border. Transformation as a real option for an area may be a politically difficult pill to swallow, but it is one that has been undertaken, in varying contexts, with success in urban areas worldwide. Indeed, the sections of the coastal areas of both Vancouver and Viña del Mar have undergone drastic changes in their respective histories, transforming from industrial to recreation focused.

As our concept of the relationship between man and our environment has evolved, so to have the paradigms through which we approach our built environment. The Cheonggyecheon River restoration project in Seoul, South Korea was one of the first internationally recognized examples of this paradigm shift. Completed in 2005, the emblematic project opened to the public a previously paved-over stream that runs through the heart of the mega-city, transforming the strip of land from exclusively transportation based to recreation/transportation, offering residents and visitors an array of social and environmental benefits. The river project also helped to increase the social-ecological resiliency of the city, providing flood protection for extreme rain events (1 in 200 year events) as well as greatly increasing biodiversity in the area, reducing air pollution for citizens, and bringing an average of 64,000 visitors daily.

One need not look outside the country for examples of how embracing transformation can increase the resiliency of a coastal area. Dichato, Chile, was one of the hardest hit localities from the earthquake of 2010, and while it suffered from the initial earthquake damage, it was hit far worse by the ensuing tsunami. The regional response to the coastal devastation caused by the tsunami, titled *Plan Reconstruction del Borde Costero de la Región Bio Bio*, was headed by Chilean architect Sergio Baeriswyl and represents a holistic approach to coastal zone security. Large portions of the border were restructured, and a new zoning category was implemented at the border in order to restrict housing and provide mitigation for the rest of the city. The new mitigation parks, beyond increasing the resilience of the city to tsunami and storm surge, increased the public spaces available to its citizens tenfold.[13] The plan maestro of Dichato recognizes the possibilities in the transformation, stating:

> *Without a doubt, the story of cities affected by the earthquake of the 27th of February will be written as before and after. In effect, will never go back to being as they were before, and by that same reasoning, it is reasonable to think that they could be even better, as long as we act with transformative purpose, with realistic administration of the available resources, and with necessary prudence when considering expectations.*[14]

These are the types of resilience building solutions that architects, planners and citizens should be looking forward towards. The development paradigms of today are powerful but restrictive, as we have seen in both Vancouver and Valparaíso. Orienting adaptation efforts towards community focused, city-system wide efforts could yield benefits in terms of long-term resilience for the future.

Endnotes

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10 Idem

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14 Idem

IX-CONCLUSION

Our investigation into the coastal regions of two American conurbations suggests that pressure on cities, both internal and external, will demand changes to the development of coastal communities worldwide, and those on the west coast of the Americas more than most. The very same topography and climate that initially made the western coast of the Americas such an attractive place to settle means those same settlements will face some of the harshest effects of climate change. Combined with the ever increasing worldwide movement towards urbanization, the question of how to approach this new reality will be the defining issue to shape our most important cities in the century to come.

Under the previous border design paradigm, the answer to steadily growing populations in coastal cities was to encroach further and further onto oceanic territory to consolidate land for human exploitation. Our findings throughout this thesis suggest that this paradigm simply will not be compatible with what the future brings.

What seems clear in general from the responses we have seen proposed or undertaken in both Vancouver and Valparaiso is that city and infrastructure resilience are viewed primarily as engineering problems. The major studies commissioned by both cities were carried out by engineering firms or entities (Northwest Hydraulic Consultants in Vancouver, Instituto Nacional de Hidraulica in Valparaiso). Recall that resilience, understood through the lens of engineering, revolves around the ability of a system to return to its original state. This approach suggests that what most concerns city governments, the threat they most wish to defend against, is change. It also suggests that while resilience is a common goal, marshalling the will to follow through with what may be difficult adaptations to truly approach a resilient waterfront is a difficult proposition.

This conservatism (used in the literally, not political sense) is not wholly unjustified. Democratically elected local governments like those in Valparaiso and Vancouver are ultimately responsible to the electorate, whose principal concern (in almost all matters) is protecting or improving their quality of life. In this sense a solution designed to maintain the status quo is not just acceptable, but perhaps preferable. The examples of responses we have seen suggest however, that what may be advantageous for homeowners and businesses in the coastal zone is not necessarily the best option for the overall system. As we've seen through our analysis of the both the coastal systems and the forces acting upon them, the demographic and environmental variables at work in the coastal borders of metropolitan areas are powerful enough that maintaining the status quo is not a realistic goal for the next 100 years.

The variables that are acting to change coastal environments, while inevitable, are still very much unpredictable in nature. This volatility in how the border may eventually change suggests a design paradigm that accommodates change and embraces unpredictability, one based on social-ecological rather than engineering resilience, presenting the relationship between sea and city not as a source of tension, but rather of opportunity. This vision of the border encourages planning that will adapt buildings and the urban fabric to accommodate changes, wherever and whenever they come. The only way to be truly resilient to a an undefinable hazard is to accept the change inherent the process of adaptation.

This thesis works to advance our understanding of how our current coastal development paradigms will be affected by climate change, and how cities will be able to share knowledge and experience across boundaries. In the course of our investigation several other themes arose that would be valuable contributions for future study. One issue that we did not delve deeply into is how the local politics effect the paradigms in place in each city. Depending on situation, this may be a critical piece into how well experience translate from one municipality to another. It should also be noted that politics, even more so that other variables, can shift quite quickly from minute to the next, so any evaluation should be on general themes rather than specifics.

One of the points that became clear during our exploration was the necessity of an overarching strategy that integrates all systems in the Social-Ecological System of the metropolitan area. A working study of what such a strategy would look like, what areas it would cover, and how it would be implemented would be a critical piece for future adaptations.

Another point mentioned in our discussion is the critical nature of citizen engagement in the process. While we provided some examples of the form this could take in Valparaíso, an in-depth study into how best to activate citizens groups and involve them in the adaptation process could be extremely valuable. Specifically in order to understand what local institutional knowledge there may be able coping with disasters, and how it can be leveraged into official planning.

Finally we mainly focused our attention on coastal defense options that fall under the category of *adapt* strategies, seeing these as the most feasible and impactful options available building resilience around a new development paradigm at coastal borders. However, further investigation into *retreat* options, would be an extremely valuable contribution to the field. As we have noted many times throughout this text, the nature of the variables that will be changing the coastal environments are very unpredictable, and even the best scientific models are still just projections; it is entirely possible that our current worst case scenarios are too conservative. In that case options that today we consider outside the realm of feasibility may become more palatable, or even necessary, and having information regarding their possible implementation would be critical.

The epigraph of thesis was taken from a man who died over 35 years ago, but he may was well have been speaking to the architects and planners of the current day. In the context of urban areas, his words read more as an ultimatum than an innocuous observation. With the evidence we have explored regarding both the potential effects of climate on coastal areas, and their level of preparedness for them, Buckminster Fuller's words carry an urgency for human settlements worldwide, and serve as a clarion call for those who would approach the challenges head on. This thesis suggests that cities, their governments and citizens alike, can embrace the role of the *architect* in coming century, and work with clients to design a new paradigm for coastal uses and development, or they can continue with the status quo, and cast themselves as *victims* of foreseen changes.

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