Geohazard Risk in South-Central Chile: A Study of Perceptions and Preparedness

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Abstract

Subduction zones produce high-magnitude earthquakes and significant volcanic eruptions worldwide, with varying event frequencies. South-central Chile is one of the most seismically and volcanically active subduction regions in the world, generating one major earthquake and four major eruptions in the past six years. This study examines perceptions of geologic hazard (geohazard) risk in south-central Chile, and explores the extent to which perceptions of risk align with actual risk. It includes a cross-sectional statistical analysis of 136 survey respondents' perceptions of geohazard risk, and a spatial Geographic Information System (GIS)-supported analysis of how perceived risk aligns with actual risk from those hazards. The findings of this study show that high perception of risk can cause high disaster preparedness. The implications of this study are far-reaching, with explorations of the ramifications of geohazard risk perception and the Pacific Northwest in the event of the potential Cascadia "megaquake". With a better understanding of what causes perceived risk to be aligned with actual risk, we can more effectively evaluate methods of hazard education, creating risk awareness, and making communities more resilient to geohazard disasters. Disaster resilience, not limited to geohazard-triggered events, is a crucial component to creating more generally resilient populations.

Introduction

After ten hours spent bouncing along the Carretera Austral and churning through Chile's Southern fjords between Puerto Montt and Chaitén, a kilometer-wide expanse of gray material jutting out into the ocean and laced with weathered stumps and half-buried houses comes into view. This sight is relatively new in the region, a product of the 2008 eruption of Volcán Chaitén, the once unassuming hill that now steams furiously just ten kilometers inland of its namesake town. The eruption caused no fatalities, except for an elderly person struck by a heart attack due to the stress of evacuation. The town was evacuated in good time, despite the fact that the volcano erupted after only 36 hours of warning tremors that increased in magnitude as the magma rose in the mountain. The successful evacuation efforts saved the lives of many residents of Chaitén, a fact that is evident by the sight of the dozens of houses that were half-buried in ash, collapsed, or carried away from their foundations by the debris-laden river flood. The volcano, still considered to be erupting, continues to steam and to build a lava dome while the town of Chaitén rebuilds below.

Before the tremors that announced the impending eruption, most residents of Chaitén did not perceive any threat from the volcano, as it was believed to be dormant and unlikely to erupt. Many did not even believe that Volcán Chaitén was a volcano, but a benign hill up the river. Had the town's residents not cooperated with the evacuation efforts, or recognized the risk to which they were exposed, the town's story may have taken a morbid turn on that day in May of 2008.

Severe earthquakes, volcanic eruptions, and tsunamis happen predominantly at this kind of plate boundary. The subduction plate boundary is common around the world, forming the edge of the Pacific Basin and the volcanically active "Ring of Fire". These subduction zones occur along countries with varying degrees of socioeconomic status, which affects those countries' ability to mitigate hazards and respond to disasters. The May 1980 eruption of Mount Saint Helens, a volcano produced by the subduction of the Juan de Fuca plate under North America, had a Volcanic Explosivity Index value of 5. The volcano produced approximately 1 km^3 of airborne ash, and killed 57 people who were nearby.[1] In 2004, the largest earthquake since the moment magnitude 9.5 1960 Valdivia event, registering as a seismic moment magnitude of 9.1-9.3, ruptured a 1500-kilometer-long section of the Indo-Australian and Eurasian plates. This subduction-generated earthquake

[1] Smithsonian Institution Global Volcanism Program, *Global Volcanism 1975-1985*. (New Jersey: Prentice Hall, 1989)

produced a tsunami that caused more than 283,000 deaths.[2] This is the deadliest tsunami in recorded history, with the 2011 Japan tsunami trailing close behind. The Tohoku Earthquake of 2011 (seismic moment magnitude 9.0) was also a megathrust earthquake,[3] and it is the fifth most powerful earthquake in recorded history. This event generated a veritable barrage of secondary effects, such as a highly destructive tsunami and the meltdown at the Fukushima 1 nuclear power plant. These three recent subduction-related events are known worldwide for the damage they caused. Events like them will continue happening at subduction plate boundaries like Chile, Japan, and the Pacific Northwest.

This study explores the relationships between risk perception and disaster preparedness in the disaster-prone setting of South Central Chile, where the list of historical earthquakes, tsunamis, and volcanic eruptions is extensive. One of the major implications this paper draws on the study of risk perception is how perception of risk influences disaster preparedness. For example, having an accurate temporal perception of risk, or the knowledge that a disaster will likely affect one's household, helps answer some important questions. Should we prepare for a big earthquake or volcanic eruption that may not even happen in our lifetime? To what extent should we invest time, money, and energy into taking risk mitigation measures, such as seismically reinforcing our homes and making and rehearsing household disaster plans? How does perception of risk inform preventative action? The setting of South Central Chile provides insights on these questions, drawing on survey respondents with recent disaster experience and compelling stories of survival. The position this paper takes is that people should, without exception, be well prepared for geologic disasters, in regions where hazard events occur frequently, such as Chile, and in regions where they happen

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[2] Lay et al., "The Great Sumatra-Andaman Earthquake of 26 December 2004," *Science* 308, no. 5725 (May 20, 2005): 1127-1133

[3] N. Uchida and T. Matsuzawa, "Coupling coefficient, hierarchical structure, and earthquake cycle for the source area of the 2011 off the Pacific coast of Tohoku earthquake inferred from small repeating earthquake data" *Earth Planets Space*, 63 (2011): 675-679

infrequently, such as the Pacific Northwest. The unpredictability of these events is only further cause for being well prepared.

Chile is frequently affected by geologic disasters, with the most damaging events being subduction-related earthquakes, tsunamis, and volcanic eruptions. The country runs parallel to the Peru-Chile subduction zone, where the Nazca Plate slips under the South American Plate at the brisk rate of eight centimeters per year (Rhea et al. 2010). The Cascadia subduction zone, by comparison, moves at about four centimeters per year (Riddihough 1984). Some scholars believe that the increased amount of seismicity in Chile works in a periodic positive feedback loop that generates increased volcanic activity and more earthquakes when seismic activity increases. (Hugo Moreno, personal communication, 2012). The particularly active period between 2007 and 2011 sparked a renewed awareness of seismic and volcanic risk in Chile. Television news agencies began to discuss earthquakes, and they even linked their monitors directly to seismographs so that earthquake alerts would show up in real time on the tagline on millions of television screens around the country. Chilean volcanologist Hugo Moreno posits that, because of all the recent seismic and volcanic activity, Chileans are now in a period of heightened awareness of risks. As the years wear on, however, these recent events may be forgotten, and people's preparedness levels will fade with the memories of the disasters.

Defining Risk

For the purposes of this study, I define risk as the objective threat to an individual's wellbeing as a result of an action. Examples include living in a place where volcanic eruptions could occur and not wearing a helmet while riding a motorcycle. A spectrum of risk helps us define the types and severity of risk. There are some actions or entities that are high-risk and high-consequence, such as riding a motorcycle without a helmet or climbing a dangerous section of a mountain. In these cases, accidents are likely to happen, and the consequences of the accidents are deadly. Others, such as the risk of being in close proximity to an active volcano that hasn't erupted for a few thousand years and is not predicted to erupt for a few hundred, are low-risk and high-consequence. The volcano is not likely to erupt, but in the case of an eruption, the consequences would be severely harmful or deadly. High risk, low consequence actions are actions that are likely to produce accidents, but not likely to produce highly harmful consequences. Low-risk, low-consequence actions are actions that are neither very risky nor likely to produce harmful consequences. In daily decisions, people tend to aim for choosing this latter type of action.

Geohazard risk tends to fall in the low-risk, high-consequence category. The chance of being affected by one of these risks is not very high, but the consequences of geohazard events to those directly affected are generally harmful. However, in places with active volcanoes, the frequency of high-consequence events increases, moving the objective risk level up.

Perception of risk plays a vital role in individuals' responses to hazards. Risk perception can be classified into two categories: understanding the risk and feeling threatened by the risk. Understanding may simply come from learning about a hazard in school, such as learning about earthquakes in a geology class. Feeling threatened may stem from having experienced a past disaster. Scholars agree that disaster experience may be a powerful influence on individuals' perception of risk, and that having more disaster experience may be positively correlated with taking more measures to prepare against future disasters (Lindell and Hwang 2008; Basolo et al. 2009; Spittal et al. 2008). Because residents of south-central Chile have experienced a relatively high frequency of disasters in recent years, it would follow that they have taken more measures to prepare for them. As research on the psychology of perceptions indicates, "perversely enough, most humans do not behave in accordance with their perceptions or attitudes" (Mileti et al. 1999). That is, a resident of Pucón, Chile who lives in a volcanic danger zone under Volcán Villarrica, may be familiar with the fact that the volcano could erupt in their lifetime, but may not take risk mitigation measures to reduce their vulnerability or plan an evacuation strategy. This incongruity between understanding risk and feeling threatened by it raises questions about how people perceive geohazard risk, and how they mitigate it, in regions where hazard events have the potential to occur often.

Risk Perception as a Determinant of Hazard Mitigation

According to Perry (1979), perception of risk is a powerful factor in determining an individual's hazard mitigation action. An individual's risk perception is said to be high if the individual understands that the risk is present, and believes the risk is threatening. A higher perception of risk can lead to a higher likelihood that an individual will act to reduce their risk. The presence of an adaptive plan, as well as the individual's definition of the risk as real and certain can also determine whether that individual is likely to take mitigation action. It is widely accepted that pre-impact evacuation is an effective way to mitigate the harmful effects of natural disasters because it removes people from at-risk zones, thereby saving lives, preventing injuries, and reduce property loss due to disasters (Perry 1979). The flow diagram in Figure 1 (adapted from Perry 1979) shows the potential number of decisions involved between the emission of an alert and the taking of an adaptive response. Using pre-impact evacuation as an example of an adaptive response, let's examine this flow diagram closely.

The event detection and information dissemination system could be as simple as an individual on a beach in Chile feeling an earthquake and knowing from experience that a tsunami may come, or it could be as advanced as NOAA's Deep-ocean Assessment and Reporting of Tsunamis (DART) buoy system. The earthquake is enough to warn the person on the coast that a tsunami could happen. The person "mills" the phenomenon—that is, reflects on past disaster experience, confirms with other people, and searches for more information, with the objective of assessing the certainty of the threat. If the threat is not real, i.e. if the earthquake was not very strong and no sirens are going off, then no action is taken. If the threat is real, then the person evaluates his or her proximity to the ocean, the sensible magnitude of the earthquake (was it a tremor or a Concepción-style quake?), and the likelihood, or certainty, of the tsunami happening. If the personal risk is low, no adaptive action is taken. If personal risk is high, the person assesses logistics by choosing a route to take, finding

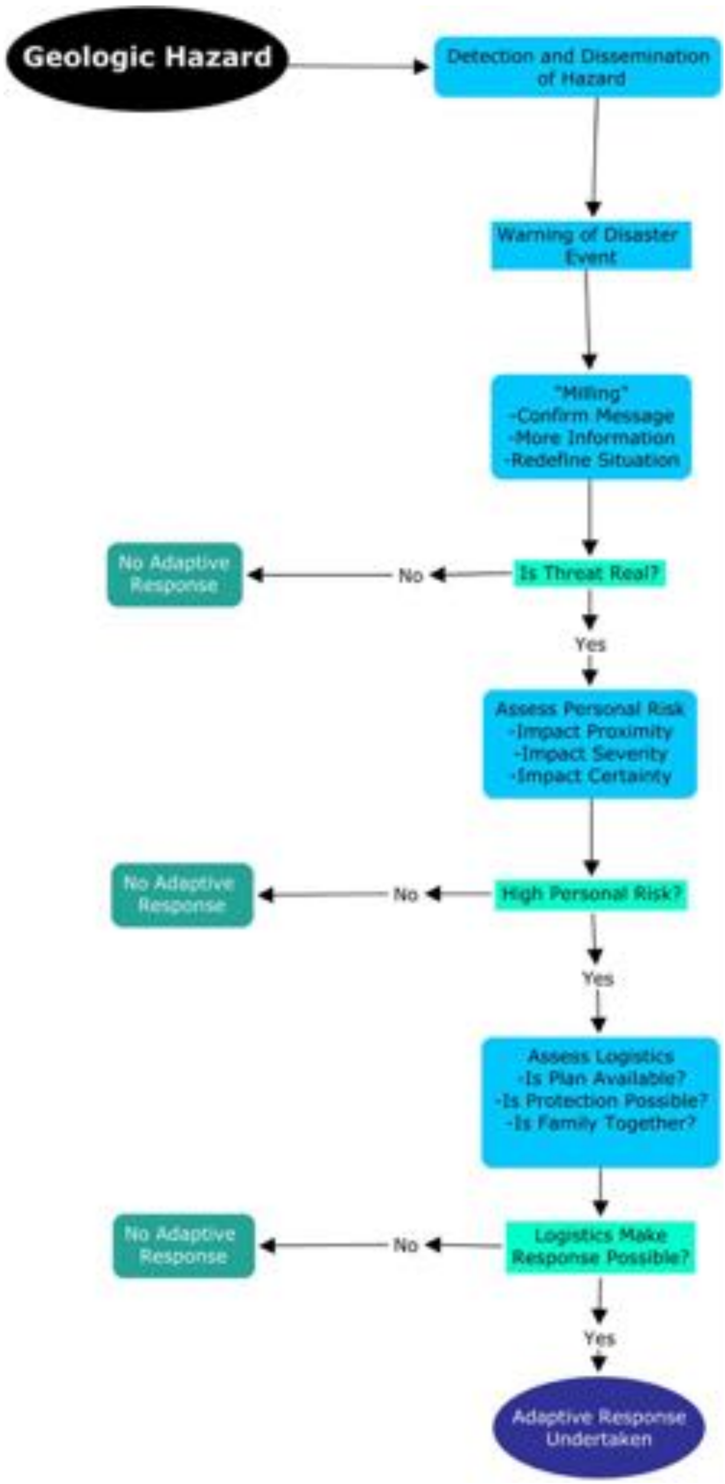

Figure 1: Flow Diagram of Adaptive Response to Geohazards (Adapted from Perry 1979).

family members, and drawing on an established plan for assistance. If no plan is in place, as in the absence of an evacuation route, no adaptive action is taken. If there is a plan in place, such as an easy-to-follow evacuation route, the person is likely to take that adaptive response and move to higher ground away from the coast. For a tsunami, this decision-making process may take place in the space of two or three seconds, and it may even be as fast and simple as the "fight-or-flight" reaction. An earthquake happens, the individual is aware of tsunami risk, and the individual escapes the hazard.

In the case of a volcanic eruption, which may be predicated by warning signs such as tremors or bulging weeks or months in advance of an eruption, the decision to evacuate may take longer, and each step in this flow diagram may involve more deliberation. In the case of a potential volcanic eruption projected to occur two days in the future, a family may wait for more information to assess the certainty of the eruption before taking any adaptive actions. Waiting for more information on an eruption is often a wise move, but waiting too long to facilitate a smooth evacuation can have deadly consequences. A careful assessment of risk, having an adaptive plan ready, and a swift evacuation are tantamount to surviving disasters.

For this study, observing patterns in perceived risk levels and comparing them to estimates of actual risk levels is key to understanding what causes people to be better prepared for disasters. Perception of risk is an important factor in determining the actions people take in everyday life. While earthquakes, tsunamis, and volcanic eruptions occur unpredictably and relatively infrequently compared to the hazards we face in everyday life, such as driving a car, they are important to consider when deciding where to live and how to prepare for disasters. To assume that a large geohazard event will not occur within one's lifetime is to ignore the overwhelming odds of death or losses due to a geohazard-generated disaster. Past research on perceptions of earthquake risk and its effects on disaster preparedness has indicated that individuals with a higher level of risk perception and disaster experience are more likely to have taken hazard mitigation measures (Basolo et al.

2009; Lindell and Hwang 2008; Spittal et al. 2008). This study aims to test that pattern in south central Chile, between the cities of Concepción and Chaitén.

The major findings of this study indicate that perceptions of geohazard risk in South-Central Chile are roughly aligned with actual risk levels, with a strong relationship between perceived risk and disaster preparedness that suggests that individuals and communities with more accurate perceptions of risk are better prepared for disasters. Furthermore, individuals who have experienced a disaster's negative effects firsthand are more likely to have taken adaptive responses. These patterns suggest that accurate risk perception and disaster experience are key factors in increasing disaster preparedness, and that disaster experience may provide the link between simply understanding a risk and preparing for it.

Structure

This paper is organized into four general sections: the first section provides the essential background information on the tectonics of subduction zones and the theoretical framework surrounding risk perception and geohazards, including the postulation of four hypotheses. The second section outlines the methodology used in the research. The third section displays the results and discusses them in detail. Within the third section, four key hypotheses are tested using Geographic Information Systems (GIS) and statistical analyses. The fourth section discusses the implications of the findings for the study area, and then explores the study's meanings in terms of worldwide subduction zones, including that of the Pacific Northwest. Finally, I suggest possible future studies based on methodologies employed in this study.

I. Conceptual Framework

To test patterns of risk perception and preparedness in south central Chile, I advance a set of related hypotheses that are tested via analysis of survey data from

136 respondents in the study area. These four hypotheses are based on the methodologies used in similar studies about risk perception, geologic hazards, and disaster preparedness (see: Lindell and Hwang 2008; Spittal et al. 2008; Basolo et al. 2009; Mileti et al. 1999).

The first hypothesis posits a positive relationship between risk perception and disaster preparedness. *Hypothesis 1: Individuals with higher perception of risk are more likely to have taken more hazard mitigation measures.* The more a person knows about a certain risk and is aware of the consequences of its effects, the more likely a person is to mitigate that risk. This is an optimistic hypothesis that contradicts the aforementioned notion that high perception of risk does not necessarily compel mitigation action. This hypothesis states that high perception of risk guides individuals toward taking mitigation measures. If true, this hypothesis will show that people are better prepared for disasters in regions where geohazard risk perception is more accurate. In testing this hypothesis, I take into account disaster experience, the respondents' perceived risk levels and mitigation efforts.

The second hypothesis explores the spatial aspects of geohazard risk perception. *Hypothesis 2: People who are exposed to higher objective geohazard risks will have higher perceptions of those risks.* That is, people living close to Volcán Villarrica or another geohazard source will have a higher, more accurate perception of risk than people living far from that source. In the same way, people living on the coast will have a higher perception of tsunami risk than people living inland. These two cases, volcanic risk and tsunami risk, seem easy to prove. Earthquake risk, however, is a different story. It is virtually impossible to predict where and when an earthquake will happen, so assigning a distance to an earthquake epicenter has only retroactive analytical value. However, relating perception of risk to places such as Valdivia and Concepción, where large earthquakes have recently occurred, is a valuable method for analyzing distance as a function of risk perception. For example, a person living in Talcahuano, which was shaken and inundated in the 2010 Concepción Earthquake, may have a higher seismic risk perception than someone living in a similar coastal town that was not as badly affected by the earthquake. Testing this hypothesis draws on the factor of disaster experience in shaping risk perception.

The third hypothesis tests the role of disaster experience and proximity to places where recent events have occurred in shaping perception of risk. *Hypothesis 3: Average risk perception will be higher in areas where significant disasters have happened in the past decade.* This isolates Chaitén and the Concepción area as places where average regional risk perception levels should be high if we accept this hypothesis. If this hypothesis holds, places such as Ancud and the Osorno region should exhibit lower perceptions of risk.

The fourth and final hypothesis tests the relationship between individuals' confidence in the government's ability effectively respond to disasters and mitigate damages. *Hypothesis 4: Individuals who have higher confidence in the government's capacity to respond to disasters are more likely to have taken fewer actions toward mitigation.* This hypothesis posits that there is an inverse relationship between disaster preparedness and confidence in the government's ability to mitigate geohazards. According to Basolo et al. (2009), "even if community residents are aware of an environmental risk, they may believe that government planning and preparation are sufficient to handle a hazard event and therefore they may feel less urgency to adopt household preparedness measures." Testing this hypothesis in the study area will allow insights regarding the government's ability to disseminate information, increase risk awareness, and support more resilient communities.

It is likely that people who have recently experienced geologic disasters will have higher risk perception than those who have not experienced a disaster as recently. The study area includes diverse geologic settings, with distinct hazard patterns. Some regions are exposed only to earthquake risk, while others are subject to seismic and volcanic risk, and still others are subject to the geohazard triad: earthquake, tsunami, and volcanic risk. In spite of the diverse hazard settings, nearly every respondent experienced the 2010 Concepción Earthquake to some degree, from Concepción itself to Chaitén, some 1700 kilometers to the south. All regions in the study area are subject to seismic risk. Earthquakes can shake any tract of Chilean land, with the strongest shaking closer to the epicenter. However, shaking from earthquakes is generally stronger closer to the coast, where the subducting plate can still produce powerful shallow-focus earthquakes.

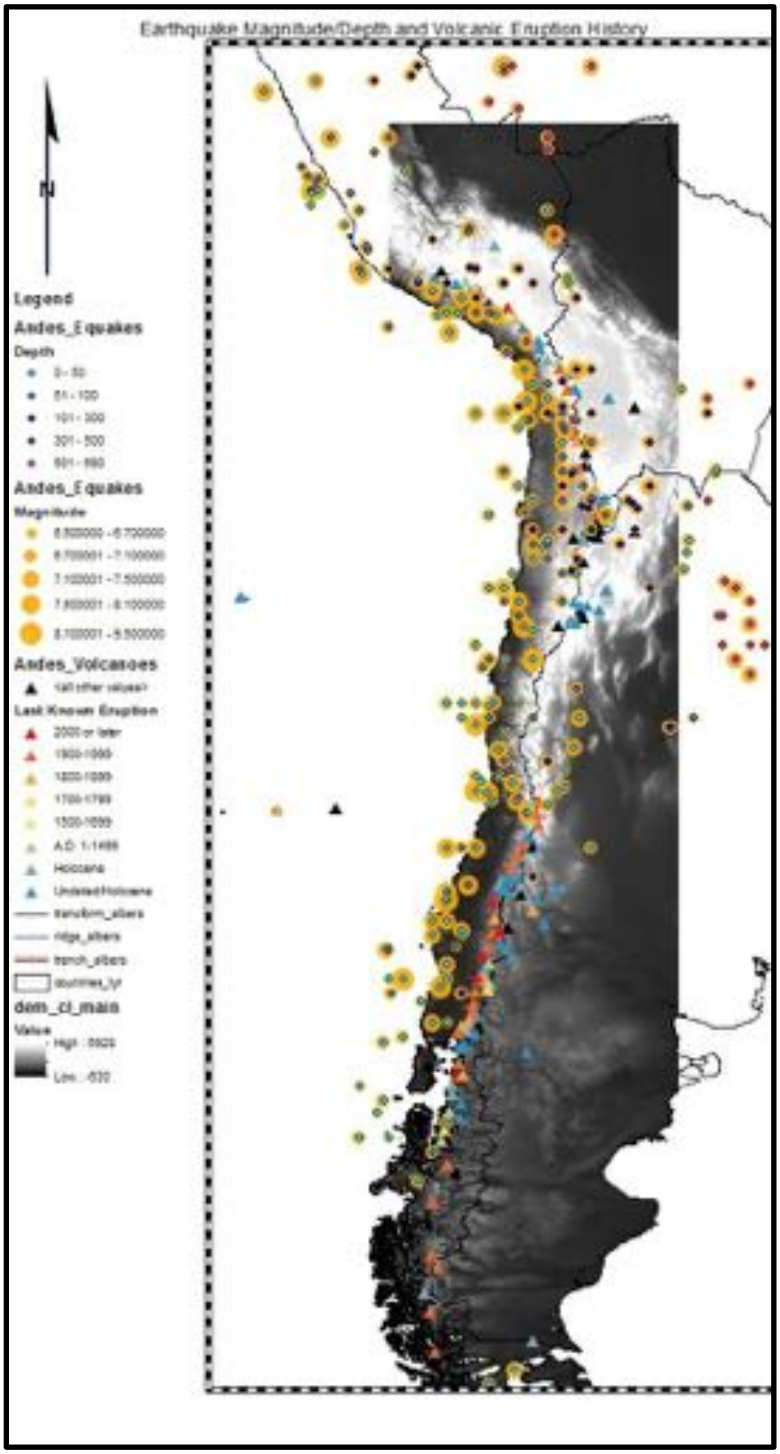

Figure 2: Overview of earthquake epicenters and historical volcanic eruptions in Chile. The study area is represented in the inset on the lower left, with major survey sites indicated. Volcano data from Smithsonian Global Volcano Project; Seismic Data from ( ); Digital Elevation Model data from NASA Shuttle Radar Topography Mission.

Earthquakes, Volcanic Eruptions, and Tsunamis: Spatial Distribution of the Hazard Triad in South Central Chile

Chile is surely one of the most geohazard-rich countries on the planet. The country spans the length of the southwestern coast of South America, and it is 4300 km long, never exceeding 240 km in width. The country's coast runs parallel to the Peru-Chile Trench, where the Nazca plate subducts under the continental plate. This subduction zone produces volcanism along the Andean Volcanic Arc, megathrust and Wadati-Benioff earthquakes, and tsunamis along the coastline. Although the Andean volcanoes have produced dangerous eruptions, the populous coastal region is at the highest risk for geohazard-induced disasters.

The map in figure 2 (above) presents a countrywide overview of earthquake magnitude, depth, and last known volcanic eruption. This map shows that shallow-focus earthquakes occur rather uniformly along the Chilean coast, and that many of these earthquakes have magnitudes higher than Mw 7.0. Earthquakes occur regardless of subduction patterns, as evidenced by the clusters of earthquakes in the volcanic gaps. There seems to be a dearth of earthquakes at the southwest archipelago of Chile, but there have been at least two in the Punta Arenas region at the southern tip. As expected, the shallow, higher-magnitude earthquakes tend to be toward the coast, while the deeper, less destructive ones tend to be further inland, in Argentina.

Earthquakes: Thrust, Compression, and Tension

Chileans have experienced large earthquakes throughout history, with over ten events with magnitudes greater than or equal to Mw 8 in the twentieth century alone (Barrientos 2007). The largest earthquake ever recorded by modern instruments, the 1960 Mw 9.5 *gran terremoto*, that jolted southern Chile, was the result of a shallow-focus megathrust slip off the coast. Shallow-focus megathrust earthquakes tend to be the most damaging events. Depending on how they displace the seafloor, these quakes can cause tsunamis, and their slip zones are often upwards of 1000 kilometers long. According to seismologist Sergio Barrientos, recurrence intervals for earthquakes MW 8 and higher are between 80 and 130 years for any given area in Chile, but for the country on the whole, these events happen about once every 12 years. Megathrust earthquakes like *el gran terremoto* occur on the order of about every 300 years (Barrientos 2007).

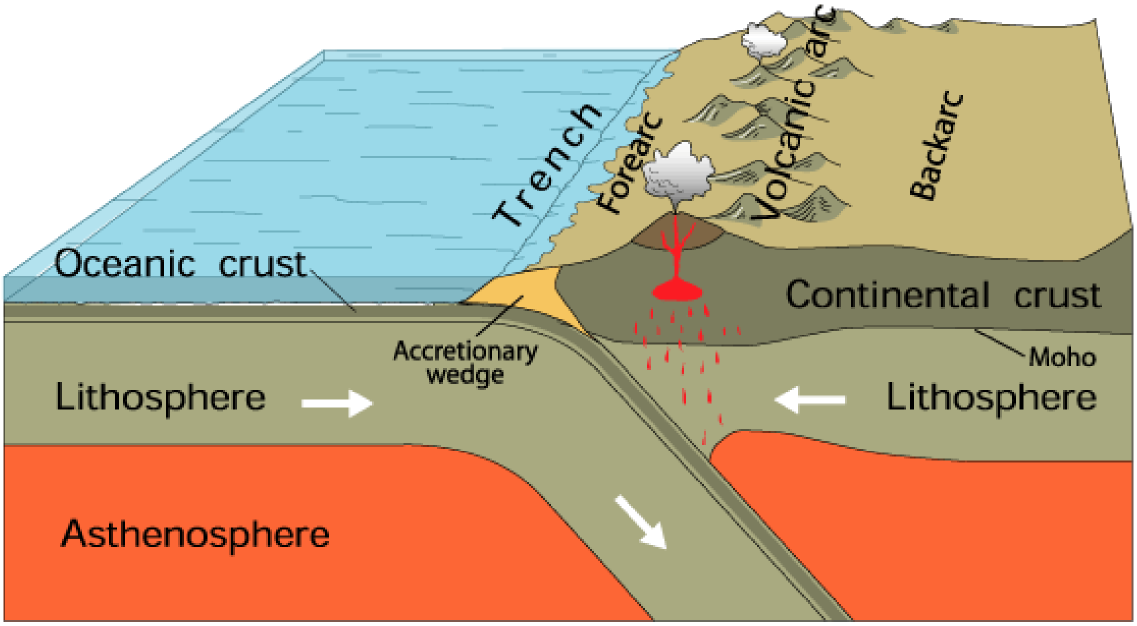

Figure 3: Schematic diagram of a subduction zone. The cold, dense oceanic crust sinks below the warmer, less dense continental crust. As it nears the hot asthenosphere, it heats up and releases volatiles that facilitate lithospheric melting, which causes magma to form and push its way to the surface, forming volcanoes. Subduction zone earthquakes can occur between about 20 and 650 kilometers beneath the surface, with shallower events generally producing stronger shaking. Image courtesy of USGS.

Barrientos (2007) states that the shorter the distance from the hypocenter to the ground surface, the stronger the shaking. Shallow-focus earthquakes occur between 0 and 50 kilometers from the surface, and because the crust has not absorbed their waves, they reach the surface and cause massive vertical, lateral and rolling movement. The seismogenic zones in Chile are well defined. Shallow-focus, megathrust earthquakes occur between 0 and 50 kilometers, significant tensional and compression earthquakes happen between 70 and 100 kilometers, and Wadati-Benioff zone earthquakes occur between 150 and 650 kilometers deep. Some very shallow events, no deeper than 20 kilometers, have occurred in the central Chile cordillera. Most of the thrust earthquakes occur off the coast, and the deeper earthquakes occur inland as a result of compression of the subducting Nazca plate (Barrientos 2007).

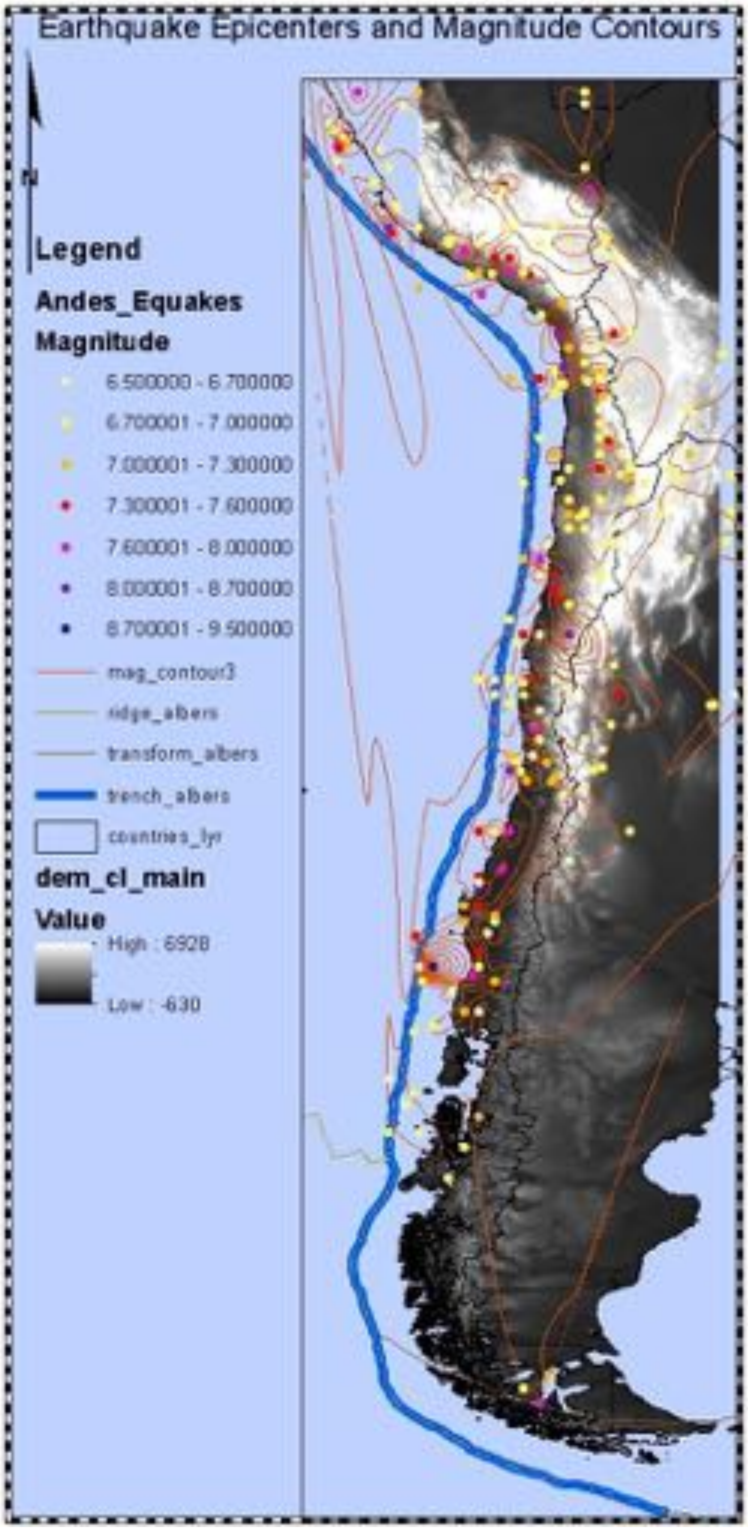

Figure 4: Map showing Mw > 6 earthquake epicenters with magnitude contour lines. The southernmost high-contour epicenter corresponds with the Mw 9.5 1960 Valdivia Earthquake. Most large earthquakes have occurred between Valdivia and the Peru-Chile border, with a large seismic gap in Southern Patagonia.

The map to the left shows epicenters and magnitude contours of historical earthquakes Mw 6.5 and above. Epicenters are shown as colored dots, according to their magnitude. The dark blue dots indicate the highest-magnitude events, and the magnitude contours provide a spatial perspective to the better show large events. The southernmost large event is, of course, *el gran terremoto* of May 22, 1960 that killed almost 6,000 people in southern and central Chile. The purple dot in the Valparaíso area corresponds to the Mw 8.2 that destroyed much of Valparaíso in 1906. This earthquake was not extraordinarily large for Chile's standards, but the fact that its epicenter was so close to Valparaíso made it extremely damaging and fatal, killing about 3800 people. In fact, between 1900 and 2000, there were 65 earthquakes with magnitudes of 7.8 or higher in the coastal and Andean region between 5 degrees north and 40 degrees south, and 28 of these were shallow-focus megathrust events (Kovach 2004). As is evident in the images below, most of the events with magnitudes greater than or equal to Mw 6.5 occur undersea or close to the Chilean coast. This emphasizes the vulnerability of the coastal area to large earthquakes and other seismogenic phenomena, such as tsunamis and landslides.

Tectonics of the Nazca, Antarctica, and South America Plates

The Andean Volcanic Arc is a product of the subduction of the Nazca and Antarctic oceanic plates under the South American continental plate. The map in Figure 5 (below) provides an overview of the spatial relationships between volcanoes and earthquakes in the Andes. In southern Chile, five eruptions have occurred since 2000. The Andes volcanoes are home to 6 of the 47 super-eruptions between the Ordovician and Pleistocene. The 2008 eruption of Chaitén, in southern Chile, was the first VEI 5 eruption of the 21st century, and due to quick action by scientists and officials, residents of areas in danger were able to evacuate (Tilling 2009).

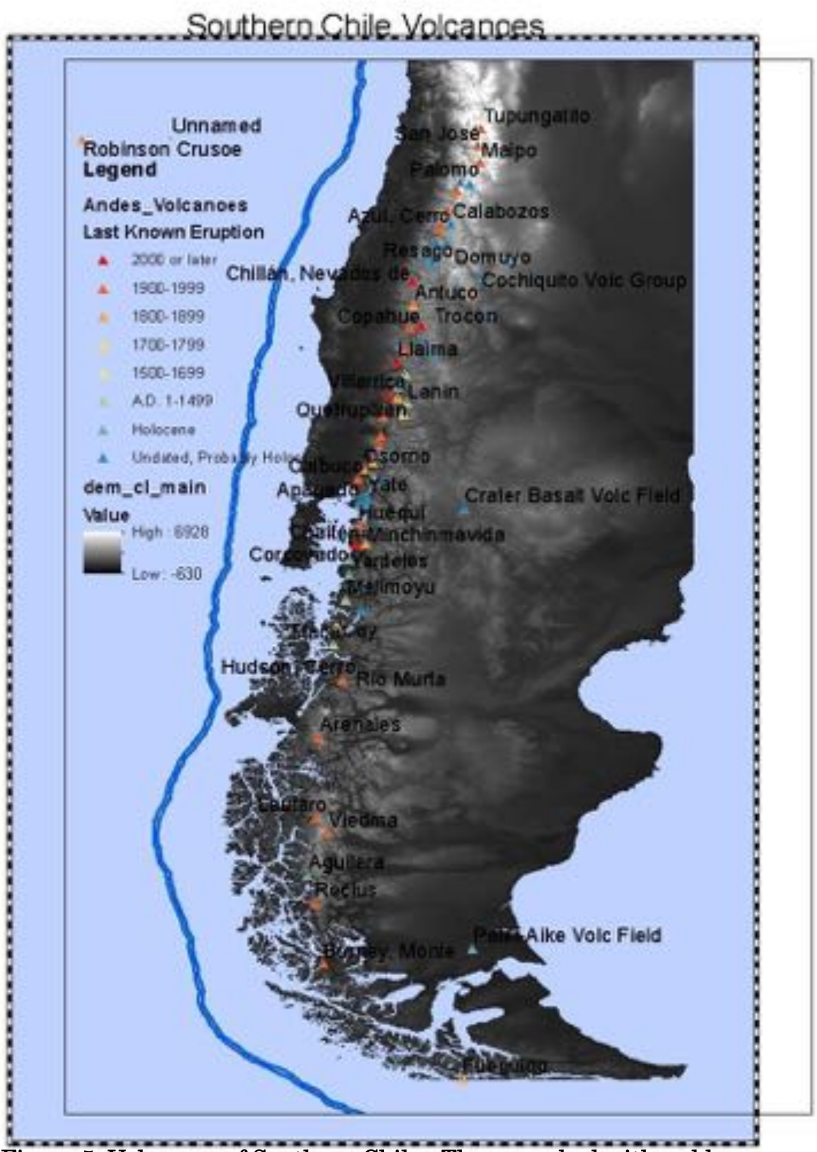

Figure 5: Volcanoes of Southern Chile. Those marked with red have erupted since 2000.

The Andean Volcanic Arc is divided into four zones: Northern Volcanic Zone (NVZ), Central Volcanic Zone (CVZ), Southern Volcanic Zone (SVZ) and Austral Volcanic Zone (AVZ). These regions are separated by gaps in volcanism due to flat-slab subduction, a type of subduction in which the subducting oceanic crust does not dive at a steep angle. It is commonly thought that flat slab subduction is the result of young, warm oceanic crust maintaining its buoyancy under the continental plate instead of sinking sharply, as ancient, cold crust would. Manea (2011) states that this is not necessarily the case for all flat-slab subduction zones. Under South America, the Nazca and Antarctica Plates are indeed relatively young, as their mid-ocean ridge sources are close to the continental plates. However, due to the colliding plates, the thick continental craton of South America has expanded trenchward, causing the asthenospheric wedge to disappear, which allows the oceanic crust to slide directly underneath and almost parallel to the continental crust. In the Andean Volcanic Arc, volcanism only occurs at points where the subducting slab achieves a downward angle of at least 25-30 degrees. We can see evidence of flat-slab subduction in the gaps in volcanism in South America. There are three such gaps, and they are between the four volcanic zones. For the purposes of this study, I focus only on the Southern Volcanic Zone. The map below presents the Central and Southern Volcanic Zones for a broader picture of eruptive history in Chile.

Geologic hazard intensity in Chile seems to be focused on the coast, where populations are at risk from earthquakes and tsunamis, and near volcanoes, where populations are at risk from earthquakes and volcanic eruptions. An in-depth regional analysis is central to understanding risk perception in these areas, and examining interregional patterns of perception and preparation is important.

II. Research Design and Methods

This study employs a combination of spatial GIS data and sociological survey data from 136 respondents to analyze perceptions of geohazard risk in South Central Chile. With the guidance of a discreet rating system, I categorize perceived and actual risk for analysis in GIS. The survey data is analyzed using t-tests, bivariate correlations, and simple descriptive statistics. Some sociological data is paired with GIS data to analyze it in a spatial context. The interdisciplinary methods used in this analysis provide a solid means to better understand perceived risk and how it compares with actual risk.

Geographic Distribution of Respondents

During the month of December 2012, fellow researcher Julian Cross and I administered surveys in populated areas between Concepción and Chaitén. Throughout the course of four weeks, we collected data in Concepción, Cunco, Pucón, Lican Ray, Villarrica, Coñaripe, Temuco, Valdivia, Ancud, Corral, Niebla, Puerto Varas, and Chaitén. The table below shows which data collection sites are obviously exposed to volcanic and tsunami hazards, along with the percentage of respondents from each hazard type area. Some respondents reside in areas not visited by the researchers, but they are included in the analysis.

Volcanic Hazard Exposure	Cunco, Pucón, Lican Ray, Villarrica, Coñaripe, Temuco, Puerto Varas	59 Respondents (43.4%)
Coastal Hazard Exposure	Concepción, Talcahuano, Valdivia, Ancud, Corral, Niebla	65 Respondents (47.8%)
Volcano/Coastal Hazard Exposure	Chaitén	12 Respondents (8.8%)

Table 1: Percentage of respondents located by hazard type. Respondents are organized into three general groups: Those exposed to volcanic eruptions, tsunamis, and volcanic eruptions and tsunamis. All respondents are exposed to earthquakes due to the subduction zone, but some are closer to surficial faults than others.

Figure 6 (below) is a map indicating the study area, with the respondents' geo-located addresses. Julian and I agreed that this study area would allow us to collect survey data from people who have experienced recent disasters like the 2010 Concepción Earthquake and the 2008 eruption of Chaitén, as well as regions such as Ancud that hadn't had recent severe disasters. We were keen to visit Valdivia, given its history as the major city most affected by the largest earthquake ever recorded. We accomplished our goal of visiting towns that had been directly affected by earthquakes, tsunamis, or volcanic eruptions, or a combination of the three, within the past 50 years. Concepción had been severely affected by the 2010 earthquake, the area around Volcán Villarrica had been subject to multiple eruptions in the 1960s and 70s, and Chaitén had been nearly destroyed in the 2008 eruption.

Because of Concepcion's recent disaster history, it was high on the list of places to visit. The 2010 Chilean Earthquake was the greatest disaster to affect Chile since the 1960 Valdivia earthquake, and we felt it was important to compare risk perception and preparedness in the foci of damage and fatalities.

We wished to visit Ancud because it was severely affected by the 1960 Valdivia Earthquake and the resulting tsunami. According to locals' accounts of the event, the fishing industry suffered terribly due to the tsunami, and parts of the city at the waterfront were inundated.

Volcán Osorno has not erupted since 1869, and its eruptive history consists mainly of basaltic and andesitic flows.[4] It is a historically active volcano, with about fifteen eruptions since the year 1575. It is capable of producing lavas, lahars, pyroclastic flows, toxic gases, and ashfall. An eruption would be very dangerous to local populations. This region was important to visit because it is an area where a volcano towers overhead, but has been silent for nearly 200 years. It is similar to Portland and Mount Hood in that way.

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[4] Moreno, H. 1999. Mapa de Peligros del Volcan Osorno, Region de Los Lagos. Servicio Nacional de Geologia y Mineria, Documentos de Trabajo, No. 11, 1 mapa escala 1: 75.000. Santiago

Since the Valdivia area is home to the focus of damage and fatalities for the 1960 Chilean Earthquake, administering surveys there was a priority. In this region, we were keen to know how disaster experience and the legacy of a great event can contribute to perceptions of risk.

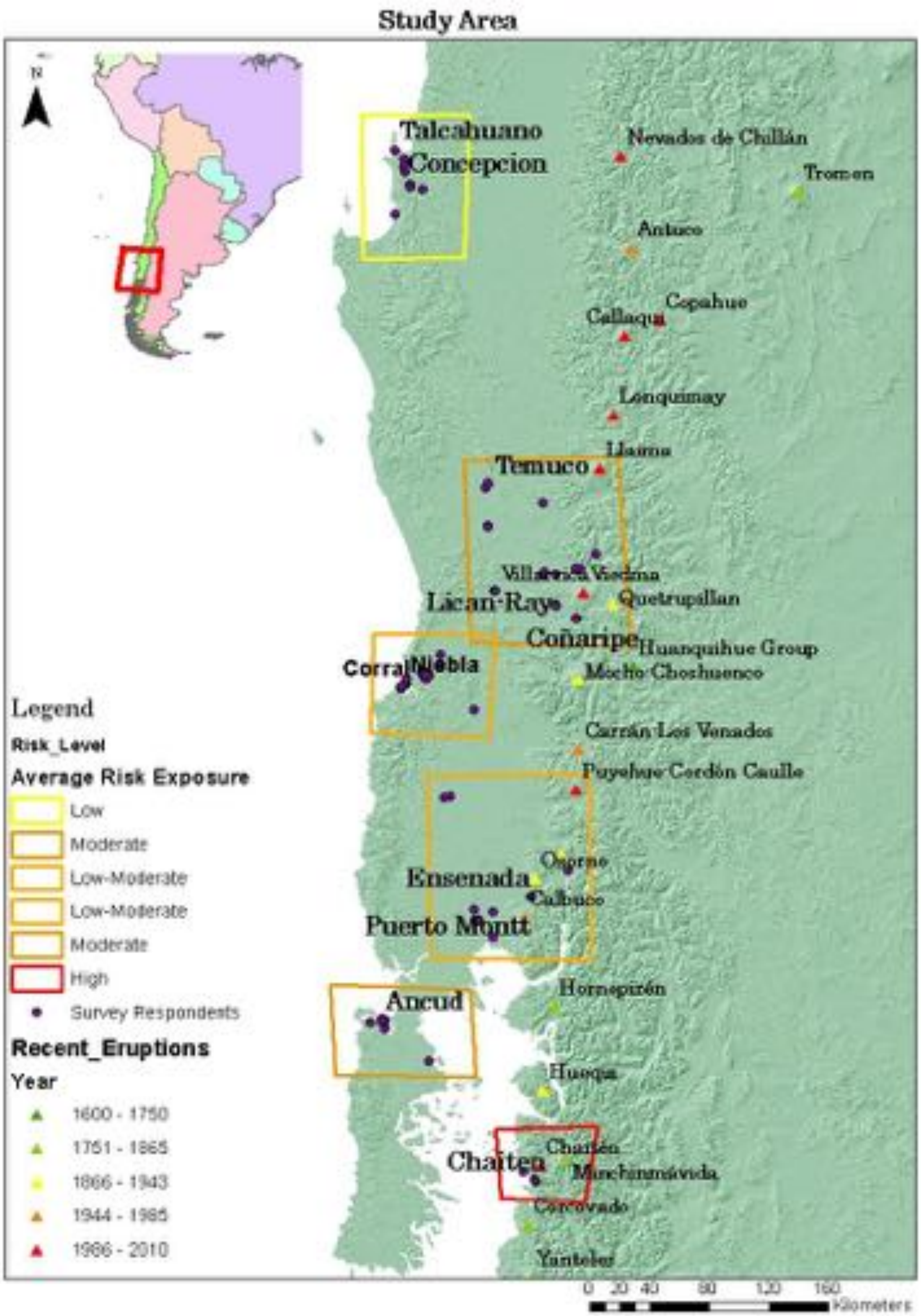


Figure 6: Study area with major cities where surveys were administered. We administered surveys during a 26-day period, starting in Concepción on December 1st and finishing in Chaitén on December 26th.

Administering the Survey

The main objective of the field study was to collect survey data from as many respondents as was reasonable. The survey was written and administered in Spanish.[5] The survey has 45 questions, and takes about 25 minutes to complete when administered orally. We administered most of our surveys in busy public places, such as parks, town squares, outside of grocery stores (with managerial permission), and on busy sidewalks. We used no system for selecting individuals to ask for participation, and tried to achieve as random a sample as possible. We aimed to ask only persons of legal age, eighteen and above. Some questions on the survey may evoke painful memories or thoughts, so we always told respondents that they were not required to answer questions that they did not wish to answer for that reason. We aimed to ask all questions on the survey, even if they did not seem pertinent to a specific region. That is, we allowed respondents to decide if they were exposed to certain risks when administering the survey, even if those risks were not at all present in their area. This entailed asking questions regarding tsunami risk perception in regions far from the sea where there is no tsunami risk.

The survey has four sections that address specific topics: the General Information section, which takes demographic and geographic data, and asks questions such as, "Have you ever considered moving due to a geohazard risk?" and, "What was the last earthquake you experienced?". The second section addresses risk perception, and asks respondents to rate their perception of seismic, volcanic, and tsunami risk for their region. The third section deals with disaster preparedness in the household, and provided the data for the preparedness level variable. The fourth and final section assesses the role of the government in hazard mitigation and the respondents' confidence in the government's ability to mitigate and respond to disasters.

[5] See appendix 1 for the complete survey in English.

The number of respondents from each region varies by the amount of time we were able to spend in each location. The ability to administer surveys was also affected by factors such as the day of the week and holidays. We collected the most respondents from the Villarrica area and Valdivia, as we were able to spend the most time in those regions and the local geography and transportation infrastructure allowed for easy travel by bus to nearby communities.

Tsunami Risk

To assess actual tsunami risk in coastal areas, I use GIS to employ an eight meter tsunami inundation line that denotes areas below eight meters in elevation. These areas would be subjected to flooding in a moderate tsunami. The inundation level was estimated based on inundation models from past studies that cite tsunami inundation levels to be six to eight meters in moderate tsunamis. The tsunami associated with the earthquake on February 27th, 2010 produced inundation of six to eight meters in the port area of Talcahuano. The inundation depth of eight meters is used throughout this analysis, since it is so commonly used in the literature (CITSU 2012, 2002, 2001; Koshimura 2011).

Respondents' perceived tsunami risk is analyzed using the "perceived tsunami inundation risk" variable, which asks respondents to rate tsunami risk to their homes on a four-point scale (exlained in table x below). If a respondent who rates tsunami risk as low also lives within the eight meter tsunami inundation zone, then their perception of risk is lower than the actual tsunami risk. Repsondents who live close to the eight meter zone are also considered to be at high risk of being affected by a moderate or severe tsunami, since variations in wave height and topography may cause different inundation patterns from the eight meter GIS analysis.

Volcanic Risk

Where possible, I employ detailed volcanic risk maps produced by Chile's *Servicio Nacional de Geología y Minería* (SERNAGEOMIN) to evaluate actual volcanic risk in the study areas. I was able to obtain and digitize maps for all volcanoes near which we administered surveys, except for Chaiten. Since this volcano was not considered a threat until it erupted in 2008, officials did not produce a map for it. A risk map of the now active volcano is underway. These maps show areas at various risk levels for lahars, lava flows, pyroclastic flows, and ashfall. They employ a standard methodology, but since each volcano produces hazards in different ways, the hazard types vary by volcano.

Respondents' perceived volcanic risk is analyzed using the "perceived volcanic risk" variable, which asks repsondents to rate volcanic risk to their homes on a four-point scale (see table x for explanation of perceived risk levels). Perceived and actual risk will be compared in the same way as tsunamis: if a respondent lives within an area deemed to be at risk for a lahar or lava flow, but they indicate a low level of perceived risk, their perceived risk does not match the actual risk they face.

Earthquake Risk

This risk parameter is more difficult to analyze, based on the availability and workability of seismic risk data in the study areas. It would have been ideal to have seismic risk maps for each town under investigation, but I was not able to find such data for most locations. I was only able to obtain a seismic risk map of the Valdivia area that shows shaking potential for the urban center of Valdivia, and an unworkable shake map of Concepcion. Since the entire study area is at risk for earthquakes, and since the accurate and detailed evaluation of seismic risk depends on having detailed geologic data, I assume a moderate level of actual earthquake risk for the entire study area. However, for Valdivia, I employ the seismic risk map in the same way I use the volcanic risk maps: respondents' perceived risk is compared to their location relative to faults and surface substrates of various consistencies.

For the sake of simplicity, I assume a moderate level of earthquake risk for the entire study area. Respondents who report a moderate level of perceived earthquake risk will be classified as having accurate perceptions of that risk. The table below illustrates the specific methodology for classifying risk perceptions and comparing them to actual risk levels.

Comparing Perceived and Actual Risk Using ArcGIS

This study employs spatial analysis to compare respondents' perceived geohazard risk to various parameters of actual geohazard risk they face. The methods are simple but effective. I examine six regions: the coastal urban area of Concepcion and Talcahuano, the region around Villarrica Volcano, the coastal and riverine region of Valdivia, the town of Ancud on the Island of Chiloe, the region around Volcan Osorno, and finally, the town of Chaiten near Chaiten Volcano. I employ various methods to analyze actual and perceived risk from tsunamis, earthquakes, and volcanic eruptions, explained below.

This study uses two indices to rank geohazard risk with GIS: a four-point, coarse scale and an eight-point fine scale. The coarse scale ranks actual risk thusly: 0 is No Risk, 1 is Low Risk, 2 is Moderate Risk, and 3 is High Risk. This scale is appropriate for actual risk because it allows geographic areas to be categorized relatively easily, and it is appropriate for perceived risk because it allows for simple categorization of perception data. Table 2 (below) compares the perceived and actual risk indices, with the criteria used to classify a respondent's location with an actual risk value.

Table 2: Rating System for Perceived and Actual Risk.

Numerical Value	Objective Risk Rating System	Interpretation of Respondent's Perceived Risk Rating
3 = High Risk	**Seismic**: Respondent located on top of poor quality surface substrate, as defined by SERNAGEOMIN.	Risk is immediate and certain, with negative consequences. Proximity to hazard ensures negative consequences in hazard event.
	Volcanic: Respondent located within 20 km of summit cone AND in topographically defined hazard zone, OR in a high-risk zone defined by SERNAGEOMIN. Direct lahar, lava, and pyroclast risk.	
	Tsunami: Respondent located inside 8-meter tsunami indundation zone and within 25 vertical meters of sea level.	
2 = Moderate Risk	**Seismic**: All regions in the study area exposed to moderate seismic risk due to the frequency of earthquakes.	Risk is certain, but not immediate. Proximity to hazard may or may not produce negative consequences in hazard event.
	Volcanic: Respondent located between 20 and 30 km of summit cone, OR within moderate-risk zone defined by SERNAGEOMIN. Moderate to low lahar, lava, or pyroclast risk.	
	Tsunami: Respondent located within 100m of 8m tsunami inundation zone and within 25 vertical meters of sea level.	
1 = Low Risk	**Seismic**: No region in the study area is exposed to low seismic risk, due to the frequency of earthquakes.	Risk is neither certain nor immediate. Proximity to hazard is not likely to produce negative consequences.
	Volcanic: Respondent located between 30 and 50 km away from summit cone. Only exposed to risk of ashfall, and in rare cases, airborne pyroclasts.	
	Tsunami: Respondent located within 1 km of 8m tsunami inundation zone and 25 vertical meters of sea level.	
0 = No Risk	**Seismic**: All regions have at least a rating of 2 for seismic risk. The value of zero does not apply to any area.	Risk is nonexistent in respondent's area, outside dangerous proximity.
	Volcanic: Farther than 50 km from summit cone. Only exposed to ashfall in rare high-volume eruptions.	
	Tsunami: Farther than 1 km from 8m tsunami inundation zone, and above 25 vertical meters from sea level.	

I classified the actual risk level to which each respondent is exposed using the Rating System for Perceived and Actual Risk, which is based on the respondent's proximity to a hazard source. Seismic risk is difficult to quantify with the present data, but given that Chile has an average of one magnitude eight earthquake every eight to twelve years, I classified the entire area to have a minimum value of "2," or "moderate" seismic risk. Only in Valdivia, where I was able to obtain a seismic risk map from SERNAGEOMIN, was I able to more accurately assess seismic risk.

The final dataset used in the GIS analysis of perceived risk, risk exposure, and preparedness includes 131 respondents, due to insufficient data from the remaining six respondents.

Computation of Key Variables

In order to obtain a more detailed and accurate view of certain respondent attributes, I computed aggregate variables from multiple questions on the survey. Instead of simply asking outright how well people are prepared for disasters, I asked more specific questions about supplies people kept in their houses, and if they had emergency plans. The following key explains how these variables are calculated.

Preparedness Level

= (Household Preparedness + Emergency Plan Readiness)/2,

where:

Household Preparedness = Mean(FirstAidKit + Extinguisher + FlashlightandBatteries + FirstAidKnowledge + FoodSaved + WaterSaved),

and:

Emergency Plan Readiness = Mean(EmergencyPlan + PlanNoGasLight + EvacuationRouteFamiliarity).

Each variable in this equation is a yes/no question on the survey, where 0 = no and 1 = yes. Household preparedness and emergency plan readiness are not weighted equally, as having an emergency plan is arguably more important in a disaster than simply having food and water stored. Since household preparedness carries six variables and emergency plan readiness carries only three, each plan readiness variable "weighs" more than the household preparedness aggregate variable. The sum of household preparedness and plan readiness is divided by 2 to achieve a final value between 0 and 1. This variable corresponds to questions 2.2, 2.6, 2.12, and 3.2 on the survey.

Risk Perception

= Mean(Perceived Volcanic Risk + Perceived Seismic Risk + Perceived Tsunami Risk)

where:

> Perceived Volcanic Risk, Perceived Seismic Risk, and Perceived Tsunami Risk employ the 0-3 scale used in Table 2.

Average Confidence in the Government's Hazard Mitigation Capacity

=Mean(Confidence in National Government + Confidence in ONEMI + Confidence in Municipality).

Where:

> All variables have a 0-3 scale. Confidence in ONEMI is calculated using the average value for each respondent of questions 4.3-4.10 on the survey.

Statistical Tests

To test for relationships between perceived risk, actual risk, and preparation level across and within regions, I employ one-sample T-tests, bivariate correlations, and simple descriptive statistics. Where the GIS analysis relies more on observing patterns among the data, the statistical analysis tests for statistical significance among variables that could help explain those patterns.

III. Results

Of the total of 136 respondents who were kind enough to take our survey, 69 are men and 67 are women. The average age of respondents is 37 years old, and the average amount of time they had been living at their current address is about 17 years. All respondents are Chilean, save one German who had been living near Volcán Llaima for about 15 years. We tried not to collect data from people younger than 18 years old, although several respondents are younger than 18. The charts below show the distribution and means of respondents' age and time living in household, which provide useful insights into the demographics of the respondents.

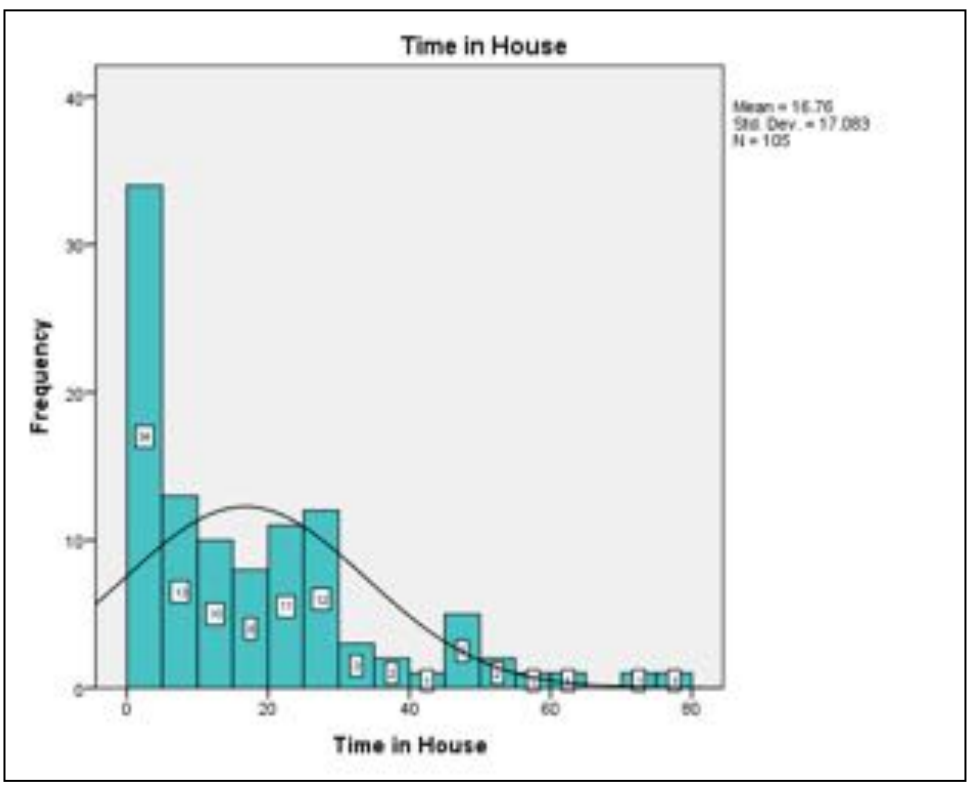


Figure 7: Frequency distribution of household tenure. The average is just under 17 years, but the sample is skewed toward 0 – 5 years. The mode is 1 year.

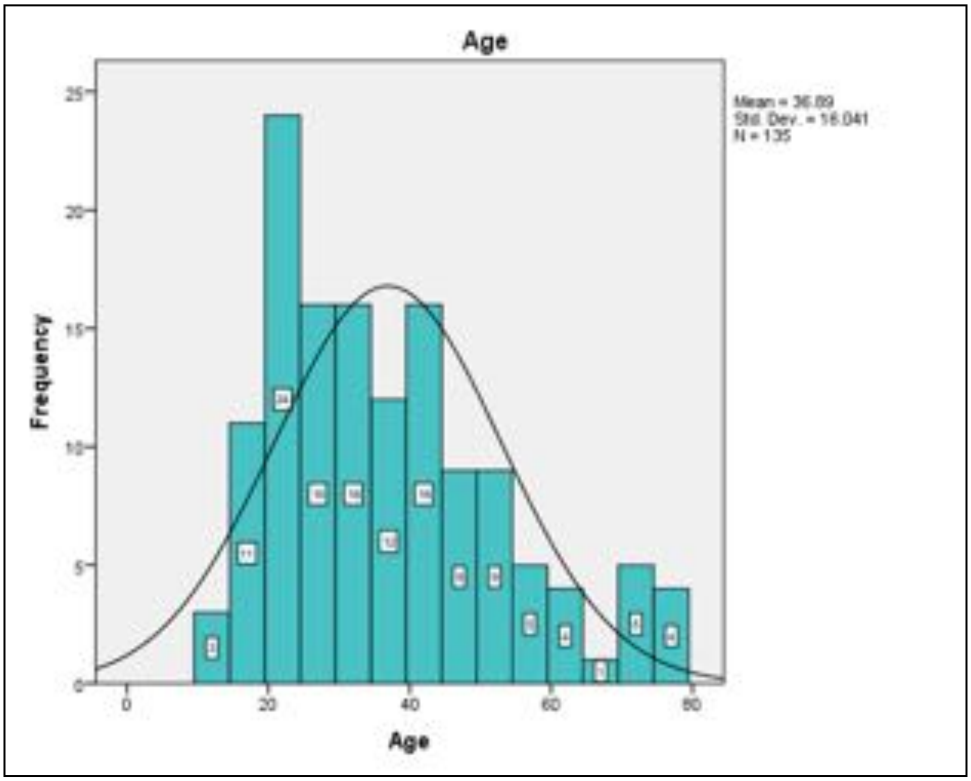


Figure 8: Frequency distribution of age. The average is just under 37, and the mode is 21 years old.

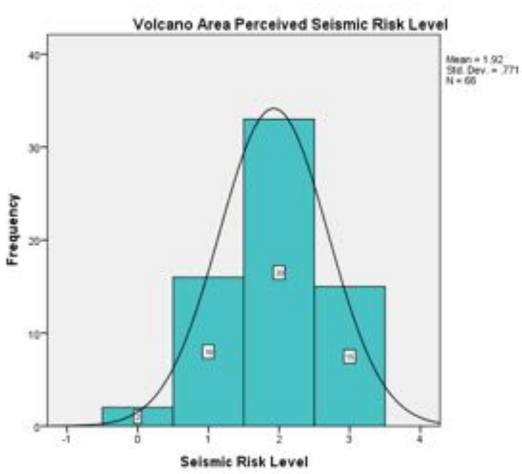
In Chile, it is common for children to live in their parents' home until they are 25 years old. When they get married, they move to a different house. This cultural norm accounts for the long household residence time in the country. I hypothesize that a long tenure in household might facilitate taking more hazard mitigation measures, such as having an emergency plan, storing food and water, and being ready for injuries with a first aid kit. Statistical studies show otherwise. As Lindell and Hwang (2008) indicate, longer household residence time may not correspond to having taken more hazard mitigation measures. Contrary to past studies, bivariate correlations run on time in house and overall disaster preparation level in the study area show that there is a significant relationship between time in house and preparedness level. People who have spent more time in their homes are more likely to have taken disaster mitigation measures.

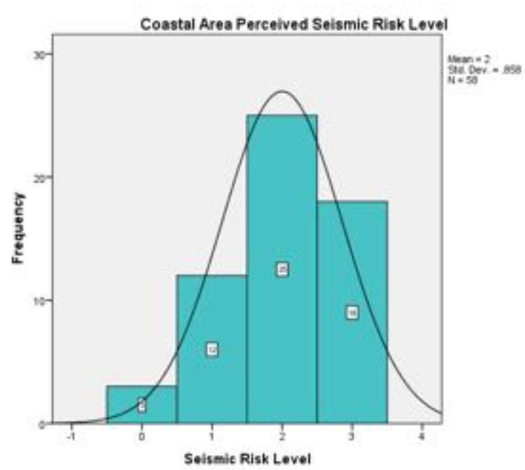
Hypothesis 1: People who are exposed to higher actual geohazard risk will have higher perceptions of risk.

The driving question of this study is that of how people perceive geohazard risk in areas exposed to varying degrees of geohazard risk. In its attempt to answer that question, Hypothesis 1 required an extensive GIS analysis of actual geohazard risk throughout the study area, which provides a base of information for analyzing patterns of perceived risk, actual risk, and preparedness level. Comparing risk perception by hazard type provides an overview of the average risk perceptions by hazard type.

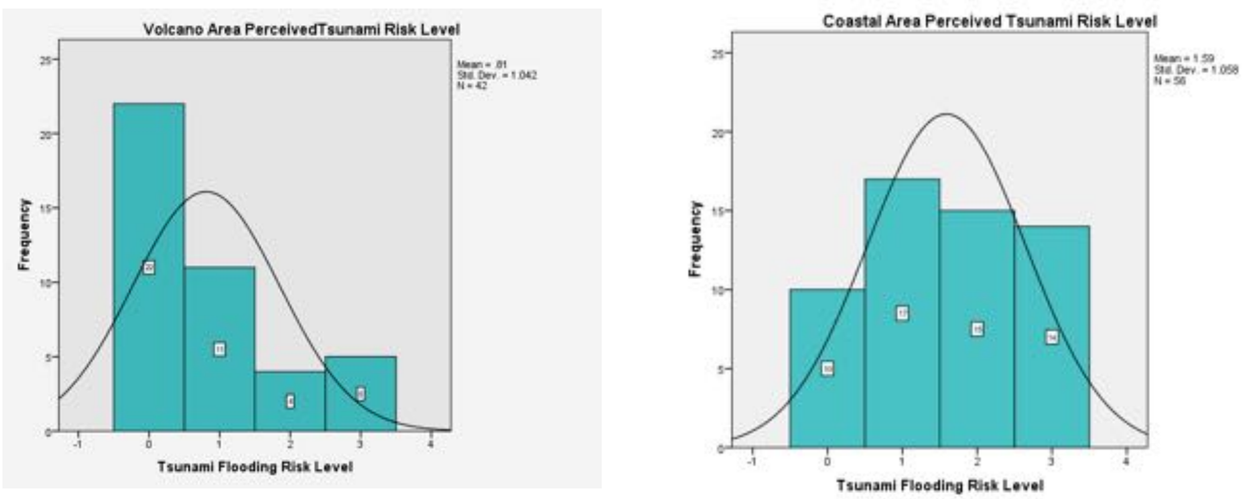
For Figure 4, Respondents were asked to rate their level of perceived risk on a 0 to 3 scale, with 0 being no risk and 3 being high risk. The responses are grouped by hazard type to reduce null answers, as would appear when assessing tsunami risk in areas far away from the coast. As expected, people in volcanically active areas perceive volcanic risk to be higher, and tsunami risk perceptions are higher in the coastal areas. Seismic risk perception is more uniform in volcanic and coastal areas, with both means close to 2, or moderate.

Seismic Risk in Volcano and Coastal Areas





Tsunami Risk in Volcano and Coastal Areas



Volcanic Risk in Volcano and Coastal Areas

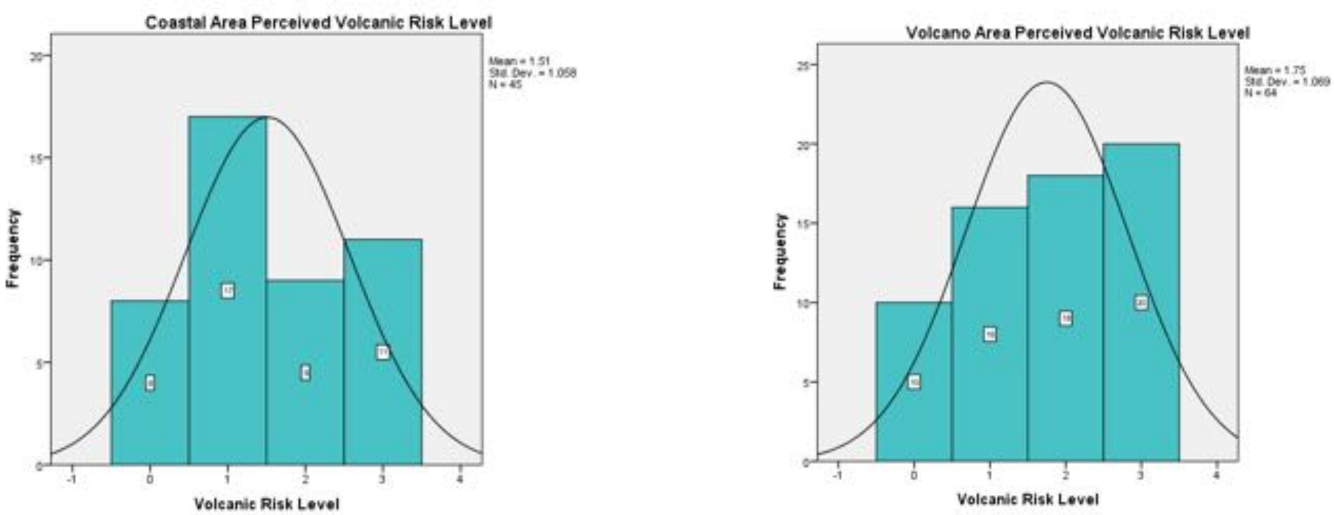


Figure 4: Perceived Risk Level by Hazard Type. Perceived Risk is measured on a scale of 0 to 3, with 0 being no risk and 3 being high risk. The bar graphs above indicate that perceived volcanic risk is higher in volcano areas than in coastal areas, and perceived tsunami risk is lower in inland volcano areas. Seismic Risk level remains about the same in coastal and volcano areas, with a mean of about 1.95. Interestingly, the mean coastal area perceived tsunami risk is only 1.59, which indicates that perceived risk is low. This could be due to the fact that many of the respondents live on hills out of the tsunami inundation zone, or that many of the coastal respondents are from Valdivia, which is a few kilometers inland of the coast, but is subject to river swelling in tsunamis.

With a general understanding of how risk perception varies by hazard type area, we can more closely analyze perceived risk and risk exposure across the study area. Figure 9 shows the perception, exposure, and preparedness levels of each area surveyed.

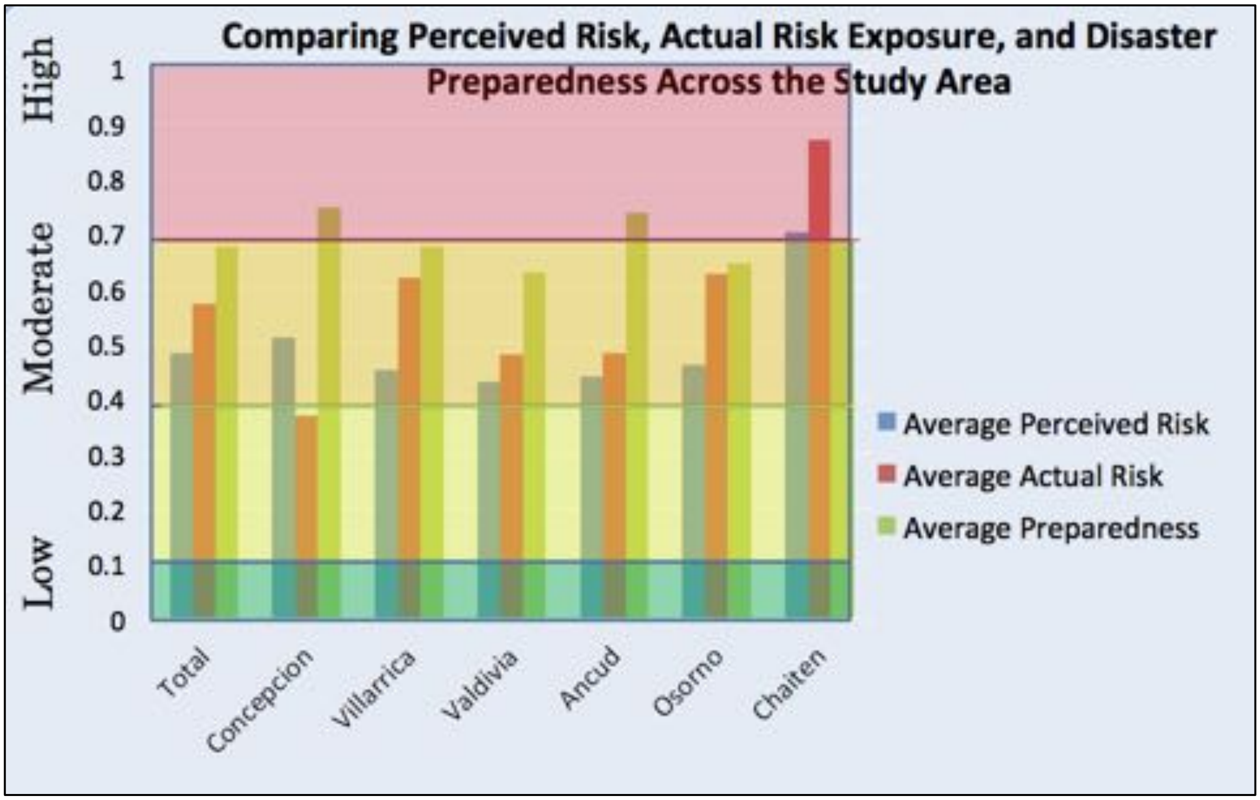


Figure 9: Perceived Risk, actual risk, and disaster preparedness across the study area. Actual risk level is the average risk exposure level of each respondent and does not necessarily reflect total geohazard risk for an area. Perceived risk is evaluated using respondents' own assessment of their risk. Preparedness is evaluated using a combination of household preparedness variables. The results are normalized for easy comparison in this figure.

Most perceived risk and risk exposure levels are within the "moderate" range in Figure 9. Preparedness levels are higher where disasters have happened in the past decade, namely in Concepción and Chaitén. Concepción has the highest relative preparedness level, scoring an average of 0.72 out of 1.0. Chaitén also has a moderately high preparedness level, but it is not the highest in the study area. Residents of Ancud were not severely affected by the tsunami, but Ancud is well prepared. Severe disasters have not happened within the past decade in Valdivia, Osorno, Ancud, or Villarrica.

Concepción

Concepción's respondents are exposed to low tsunami risk and moderate seismic risk. Few of the respondents are located near the ocean, and only a few of them live near the eight-meter tsunami inundation line. In Concepción, the 2010 earthquake severely affected the residents' perceptions of risk. The average seismic and tsunami risk perception in Concepción is moderate, but half of the residents of each era indicate high tsunami and seismic risk. Concepción has not only the highest perceived-to-actual risk ratio (moderate perceived, low actual), but also the highest preparedness level. Eight of nine respondents are somewhat or very anxious about tsunamis, while two of four are somewhat or very anxious about earthquakes. None of the respondents live within the 8-meter tsunami inundation zone, but four live close to it. A surge or a larger tsunami could affect their homes. It is not surprising that most respondents are anxious about tsunamis, because Talcahuano was heavily damaged during *El Veintisiete.*

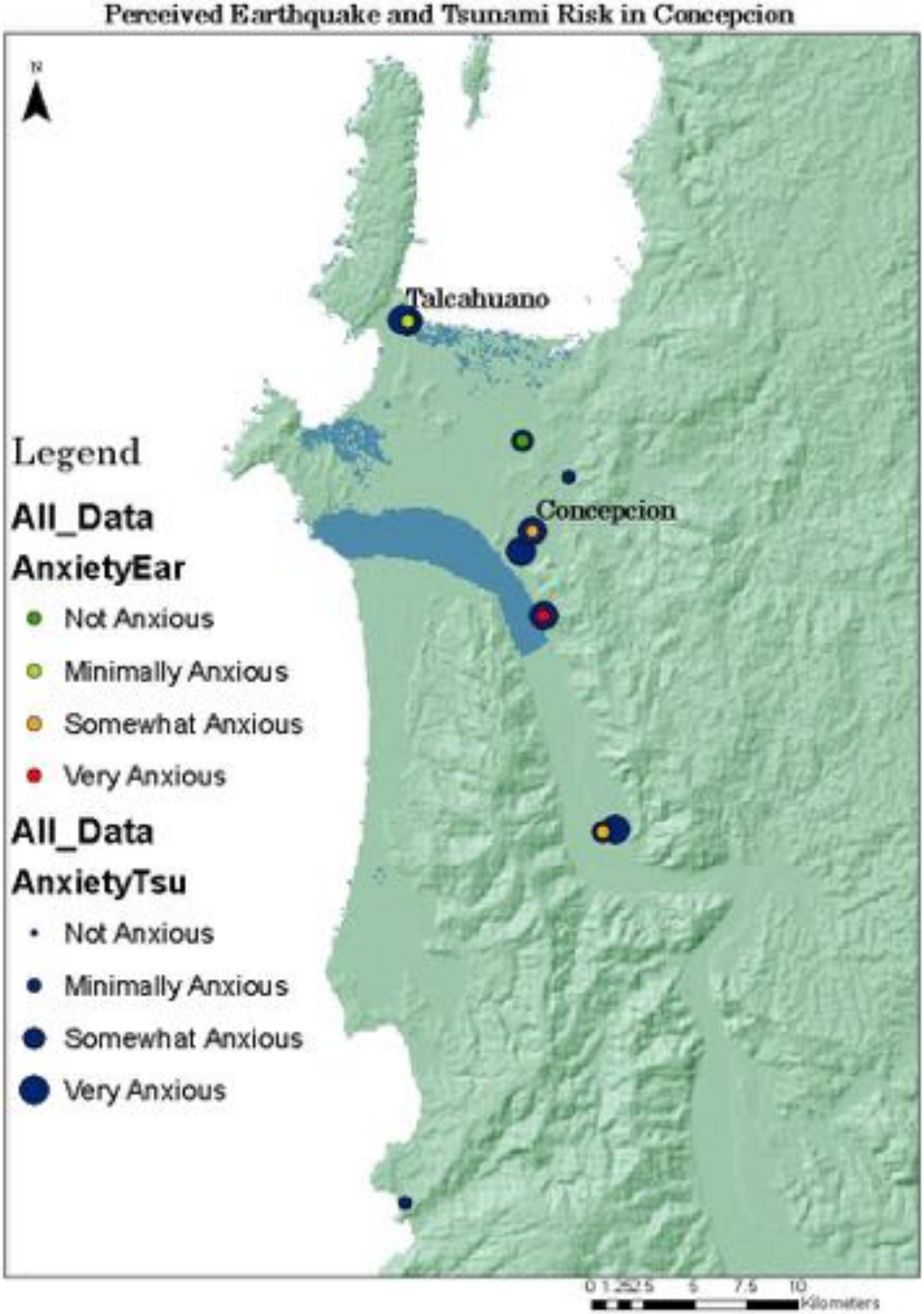


Figure 10: This map of Concepción and Talcahuano, site of the February 27, 2010 Earthquake, shows respondents' anxiety toward tsunamis and earthquakes. In this region, I use "earthquake anxiety" and "tsunami anxiety" variables to represent earthquake and tsunami risk perception, because the earthquake and tsunami risk perception variables had not yet been incorporated into the survey.

Volcán Villarrica

The respondents near Volcán Villarrica are exposed to an average of moderate seismic risk and high volcanic risk. Villarrica Volcano, which had its last major damage-causing eruption in 1971, is among the most active in the Andes. Despite the high-risk exposure in this area, average perceived risk is low-moderate. This could be attributable to the fact that the towns near Villarrica rely heavily on tourism for revenue, Pucón in particular. Pucón has a strong volcanic hazard mitigation system and alert network that the local residents support by participating in large-scale simulations of volcanic eruptions. We noted that most respondents seemed well aware of the volcanic hazard in the area and spoke confidently of being prepared and having high perception of risk.

Most respondents in the Pucón and Villarrica area indicate low to moderate risk perception. Coñaripe's respondents indicate a higher level of perceived risk, which could be attributed to the fact that the town was almost destroyed when a lahar swept through it in 1964. Lican-Ray has not seen the kind of devastation that Coñaripe has, which may explain why respondents from there do not indicate high risk perception. Dark pink indicates severe lahar risk. Light pink indicates moderate lahar risk, orange indicates lava flow risk, and yellow indicates low lahar risk. Lican-Ray is exposed to moderate lahar risk and Coñaripe is exposed to high lahar risk.

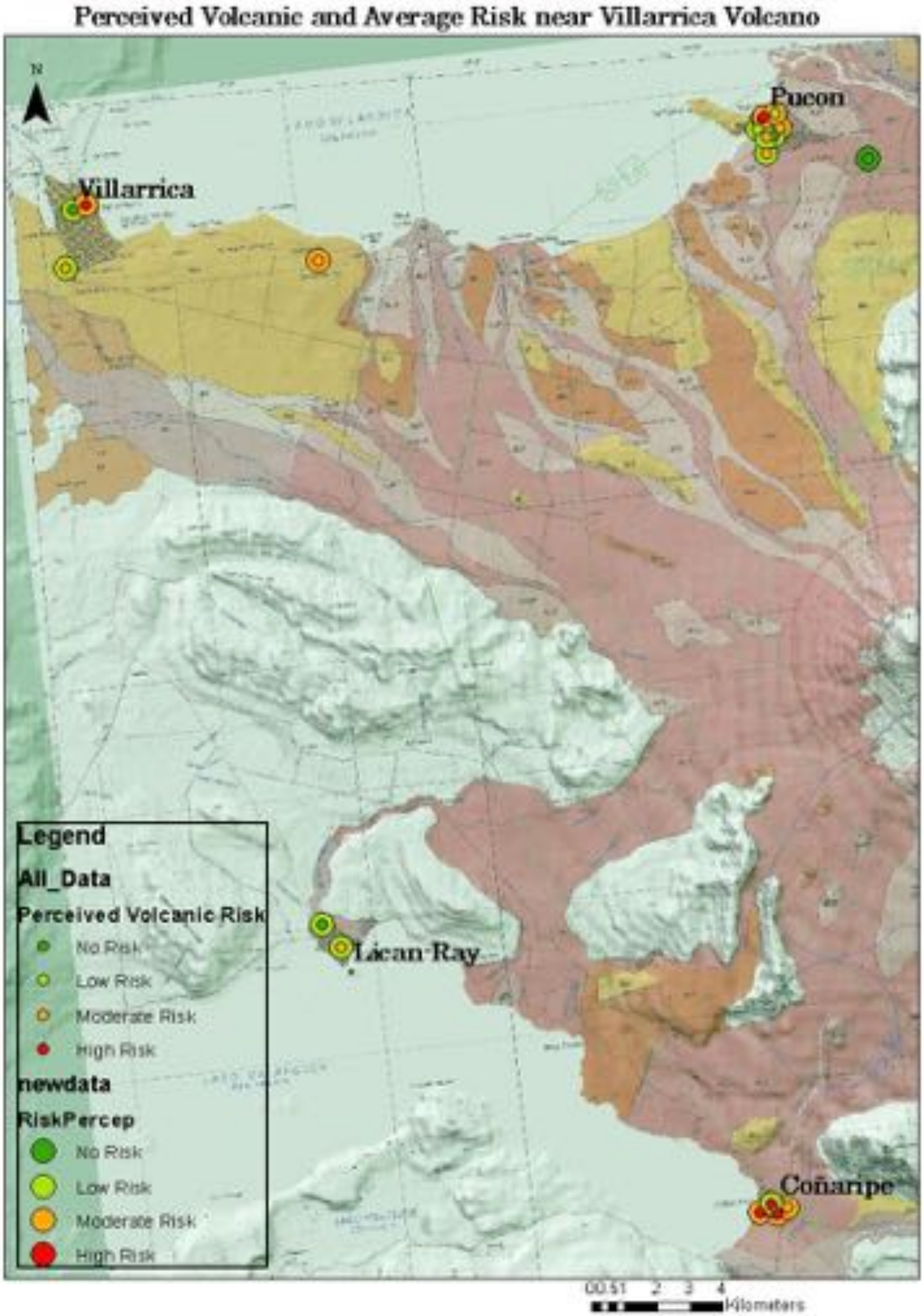


Figure 11: Central colored points represent respondents' volcanic risk perception, and outer colored rings represent the average of volcanic and seismic risk; in Villarrica (top left), Pucón (top right), Lican-Ray (bottom left), and Coñaripe (bottom right). Volcano Risk Map Image courtesy of SERNAGEOMIN.

Valdivia

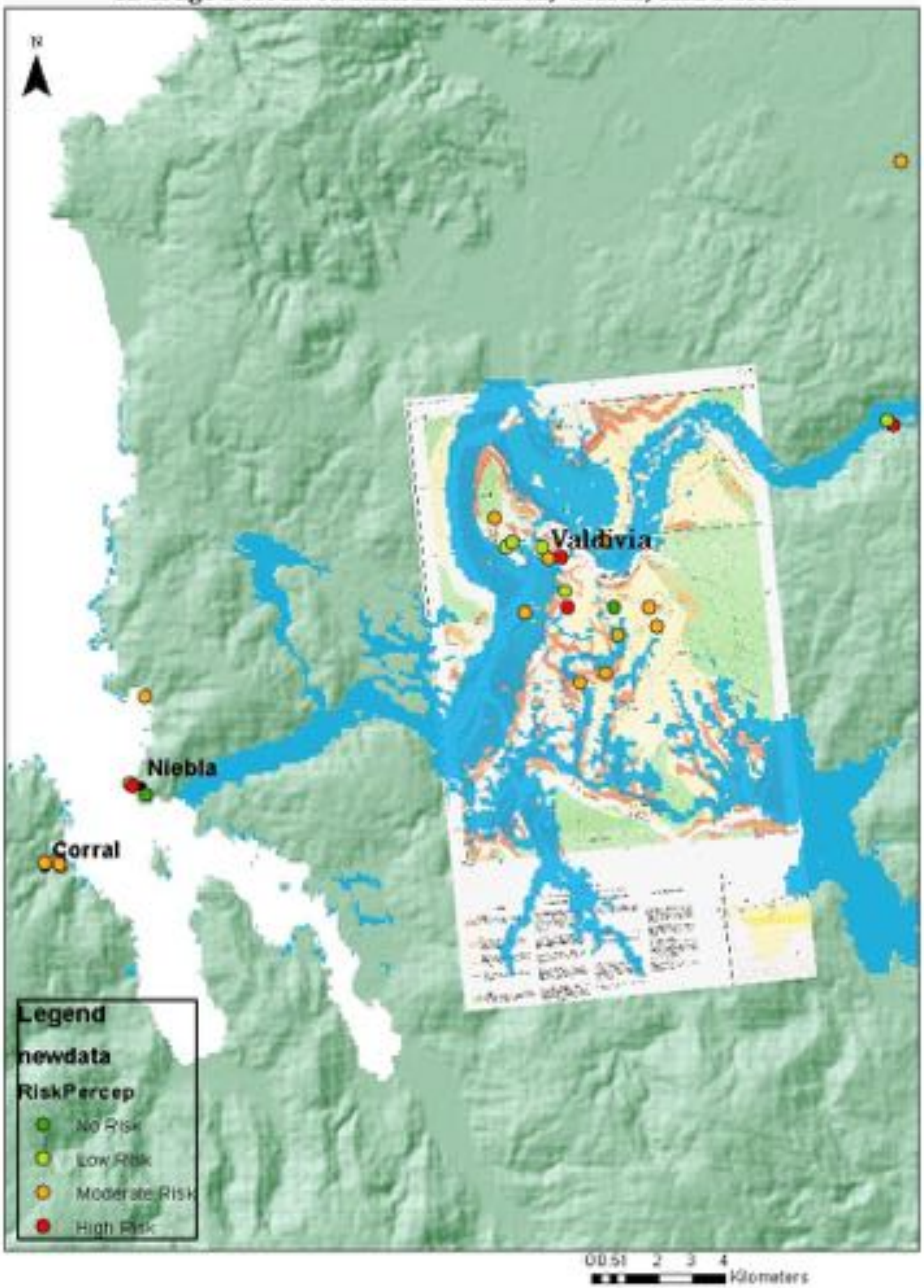
The respondents in Valdivia and the nearby coastal hamlets of Corral and Niebla are exposed to moderate average seismic and tsunami risk. Valdivia is located approximately 14 kilometers inland of the coast. A river winds through it, and widens to form a marshy plain shortly outside the town. It is exposed to some tsunami risk, as this plain and the river itself are likely to swell and cause flooding in the city, as happened in the 1960 earthquake and tsunami. Since much of Valdivia is built on unconsolidated artificial infill implemented to reinforce the marshy sediments underfoot, residents who live in houses built on the fill are exposed to high seismic risk.

Corral and Niebla are built on rocky coastal cliffs, and most residents of these towns fortunately live above elevations at risk for tsunami inundation. Only one of the surveyed residents of Corral lives near the tsunami inundation line, and none of the respondents of either town live within the tsunami inundation line. These communities are situated on top of shallow surface substrate with the bedrock close below, which reduces the effects of earthquake shaking.

Valdivia is located about 100 km from the epicenter of the 1960 Chilean Earthquake, and its older residents remembered this event and spoke of it as if it were yesterday. Although the disaster experience level in Valdivia is low among younger residents, those older than 55 remember the event. The legacy and the story of the earthquake lives on in Valdivia families, and many young respondents talked of their parents or grandparents' experiences in the earthquake. While disaster experience is low, the legacy of the event lives on in Valdivia.

Figure 12 (below): Perceived and actual seismic risk in Valdivia, based on map showing suitability of soil for construction. Areas shaded red are very poorly suited to construction, and thus have a high potential to shake in an earthquake. These soils include unconsolidated gravels and sands, and artificial infill. Yellow areas are bad for construction but better than red; beige areas are satisfactorily suitable.

Average Perceived Risk in Valdivia, Corral, and Niebla



Many respondents from Valdivia mentioned that the artificial fill used to fill in sections of the city has the potential to liquefy during an earthquake, and is more dangerous for buildings. Five of sixteen respondents indicate high perception of seismic risk. Four of those five live on land that is considered to be very dangerous in the event of an earthquake. Seven of sixteen respondents indicate moderate perceived seismic risk, and most of them live in areas considered to be relatively stable in an earthquake. Four of sixteen respondents indicate low perceived seismic risk. Three of those respondents live in areas considered to be very unstable during earthquakes. Respondents in Corral and Niebla, the two small towns to the west of Valdivia, inhabit homes that are high above the 8-meter tsunami inundation line. Corral and Niebla are located on coastal shelfs that back up to steep hills. During the 1960 tsunami, the river at Valdivia flooded, but the flooding was not as extensive as this model suggests. A real tsunami would be absorbed by the 8 kilometers of thick marshland between the mouth of the river and the city, as happened in the 1960 tsunami.

Ancud

Ancud is exposed to moderate seismic and tsunami risk. Average perceived risk is roughly equal here, in the moderate range. Ancud has one of the highest preparedness levels of all the regions, which could be due to the strong disaster experience levels among the respondents. Ancud's residents live both near the sea and in the hills. Ancud's topography is hilly, with a small margin of the populated area at sea level.

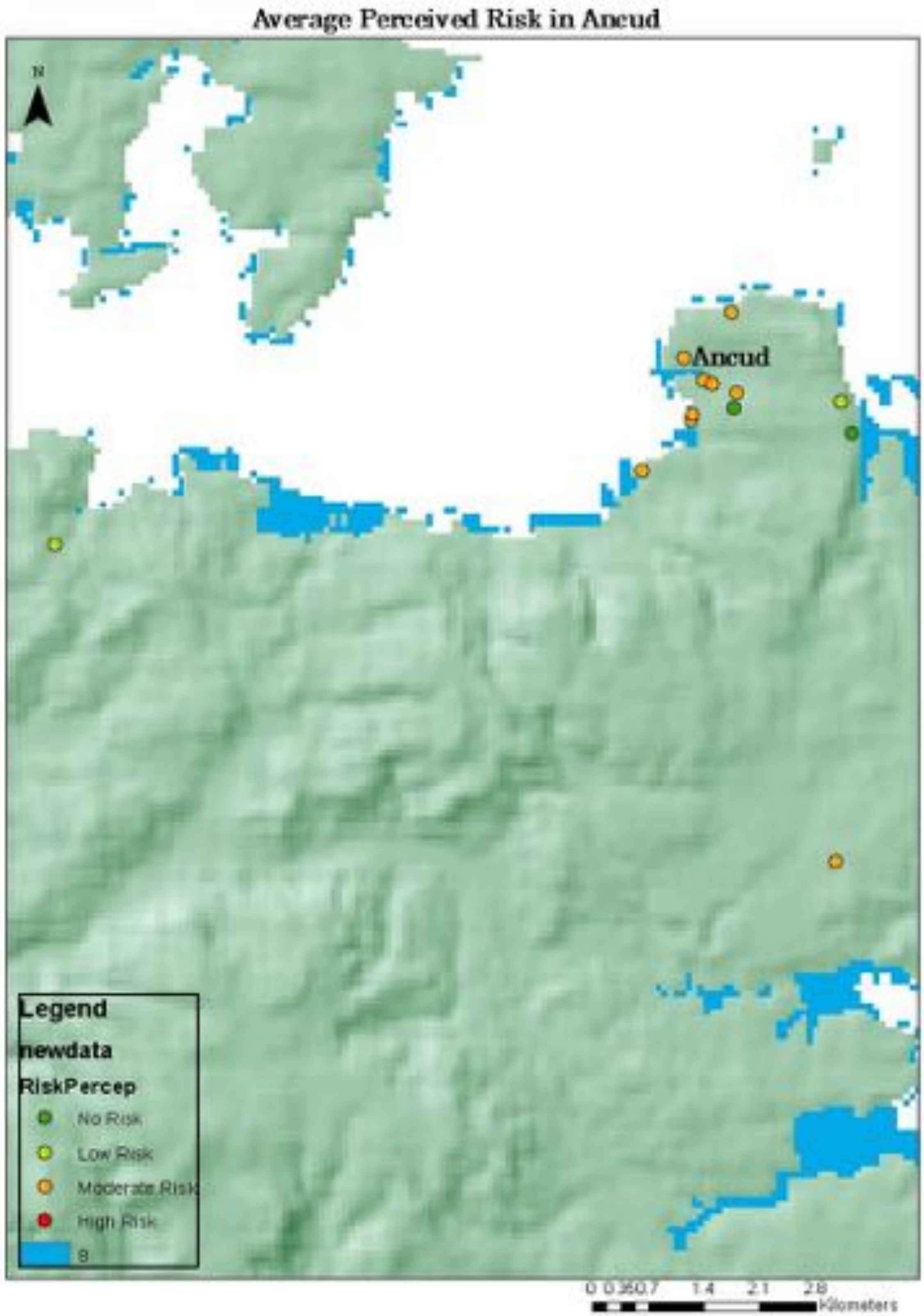


Figure 13: Perceived Risk Values in Ancud are low to moderate, with low to moderate risk exposure.

Volcán Osorno

The respondents near Volcán Osorno are exposed to moderate seismic and high volcanic risk. Most respondents live within 10 km of the summit cone, putting them directly in the path of lahars and lavas. Ensenada in particular is at high risk of being covered by lavas during eruptions of adventitious vents, and low probability of being affected by lahars.[6] The volcano has not been active for over a century, but its respondents exhibit low-moderate perceived risk and are exposed to moderate-high actual risk. Preparedness near Volcán Osorno is moderate, but relative to the rest of the regions, it scores low. This could be due to the fact that none of the respondents in this area were alive for the volcano's last eruption, in 1835.[7] Since Osorno has not erupted within the past 50 years, it is not as dangerous as Villarrica or Chaitén, which have been continuously active for the past few years. But, many respondents from this area live directly in the path of potential lava flows and lahars.

[6] Hugo Moreno, Mapa de Peligros del Volcán Osorno. Servicio Nacional de Geología y Minería, 1999
[7] Stern et al., "Volcanoes of Chile," in *The Geology of Chile,* 2008

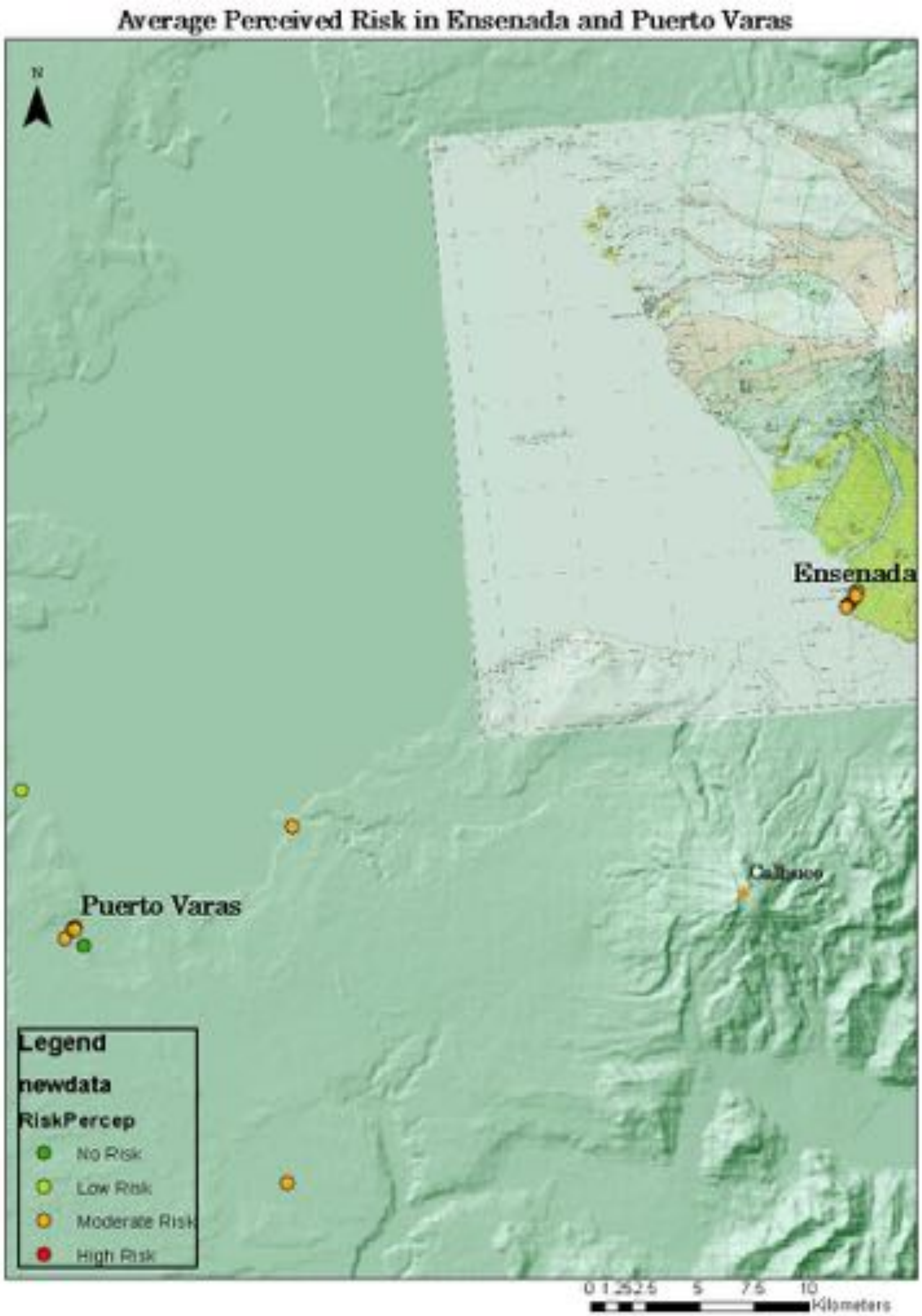


Figure 14: Perceived and Actual Risk in the Osorno Region. The town of Ensenada (middle right) is at high risk of being covered by lavas during eruptions of adventitious vents (green stripe), and low probability of being affected by lahars (yellow).

Chaitén

The town of Chaitén is located directly in the mouth of the river valley that drains the active Volcán Chaitén, putting its respondents at high volcanic risk. Because of its proximity to the ocean, the town is also exposed to tsunami risk in the event of a tsunami greater than eight meters. Chaiten has the highest average actual risk value at 0.86 (high risk), as well as the highest perceived risk value at 0.69 (moderate-high). Since the average risk exposure is in the "high" range, it is not surprising that perceived risk is high as well. The traumatic 2008 eruption likely raised perceptions of volcanic risk after half the town was destroyed and many people were without homes.

Since the town of Chaitén is located directly in the drainage of Chaitén Volcano about 10 kilometers from the volcano, and because the volcano is still building a lava dome, I consider the town to be exposed to high volcanic risk. In the image, the path of the river-carried debris flows is clearly visible. The entire town was buried in at least a meter of ash, and up to eight meters of volcanic mud. The visible debris fan extends from the town to two kilometers into the bay. Not surprisingly, eight of nine respondents from Chaitén rate geohazard risk (from tsunamis, earthquakes, and eruptions) to be moderate or high. This town is at high risk of being affected by eruptions evidenced by the large amount of gray volcanic material in the streets, left by the 2008 eruption and debris flood. Six of the ten respondents who answered the questions for the Risk Perception variable indicate that they are at moderate to high risk where they live. Four respondents indicate a low to moderate perception of geohazard risk. Most respondents are somewhat prepared for a disaster, and it is interesting to note that the two who reported high risk perception are also the least prepared.

Figure 15: Perceived and actual risk in Chaitén. The blue area shows the eight meter tsunami inundation line. None of the respondents are directly in the inundation zone, but three of them are only about ten meters away.

Hypothesis 2: Individuals with high perception of risk are more likely to take more mitigation measures than people with low perception of risk.

This hypothesis addresses the relationship between risk perception and disaster preparedness. To test this hypothesis, I evaluated the same preparation level and risk perception variables as in Hypothesis 1. On the survey, respondents were requested to indicate which disaster preparation measures they had taken from a list of household preparedness measures and several emergency plans. The measures include having extra food and water stored for disasters, having a fire extinguisher, knowing first aid, having a first aid kit, having an emergency plan/ family meeting spot, an electrical blackout plan, and knowing evacuation routes. The table below presents the mean level of preparedness across the sample size. The sample size ranges from 110 to 133, depending on missing data. The value of zero indicates a "no" response to having taken a mitigation measure, and 1 indicates a "yes" response. Mean values above 0.5 indicate that the sampled population has taken more than half of the prescribed mitigation measures.

Average Household Preparedness and Emergency Plan Readiness

	N	Minimum	Maximum	Mean	Std. Deviation
Flashlight and Batteries	117	0	1	.91	.293
First Aid Knowledge	131	0	1	.76	.431
Evacuation Route Familiarity	110	0	1	.75	.438
First Aid Kit	133	0	1	.69	.464
Food saved	133	0	1	.68	.467
Emergency Plan	131	0	1	.66	.474
Water Saved	118	0	1	.66	.475
Plan No Gas/Light	130	0	1	.59	.493
Extinguisher	132	0	1	.40	.492
Valid N (listwise)	106				

Table 3: Household preparedness and emergency plan readiness. Values of 0 mean that respondents have not taken a certain measure, and values of 1 mean that they have. The mean value shown represents the average of all responses on a scale of 0-1, with 1 being most prepared and 0 being least prepared. Seven of the eight measures present values of greater than 0.5, indicating that the majority has taken these measures. The only

value below 0.5 is having a fire extinguisher, which indicates that fewer than half of the respondents have a fire extinguisher. This result is troubling, because most Chileans heat their homes using radiant, gas-fueled heaters that often have burning flames. However, these heaters generally are equipped with automatic shutoff devices that activate when the heater is shaken, as it would be in an earthquake. Ninety-one percent of respondents have flashlights with batteries, and 66 percent indicated that they have emergency plans.

Average risk perception was measured using the Risk Rating Scale on page 27. Average tsunami, volcano, and earthquake risk perception values were averaged in order to determine the average risk perception level of the entire sample of 136 respondents.

The 133 respondents who answered the preparation level question indicate that they have taken 67% of the measures suggested. The average cumulative risk perception level, on a 1 to 3 scale, is 1.59. This indicates that the average risk perception level of the 133 respondents who answered this question is low to moderate.

A final count of 131 respondents was used in the statistical analysis of preparation level and risk perception, due to the missing data count for the remaining five respondents. A bivariate correlation of ordinal versions of the preparedness and perception variables yields a p-value of 0.033, significant at the 0.05 level. This suggests that there is a strong relationship between risk perception and preparedness, meaning that people with higher risk perception are more likely to have taken more disaster preparation measures.

Hypothesis 3: Average risk perception is higher in areas where significant disasters have happened in the past decade.

Testing this hypothesis relies on simple observations of patterns of risk perception in areas with recent disasters. Concepción and Chaitén have both experienced the most recent disasters, followed by Villarrica, Valdivia, Ancud, and Osorno. Perception of risk is indeed higher in Concepción and Chaitén, as these two regions carry the highest average perception values. Figure 15 below shows the relationship between most recent disaster and regional average peceived risk.

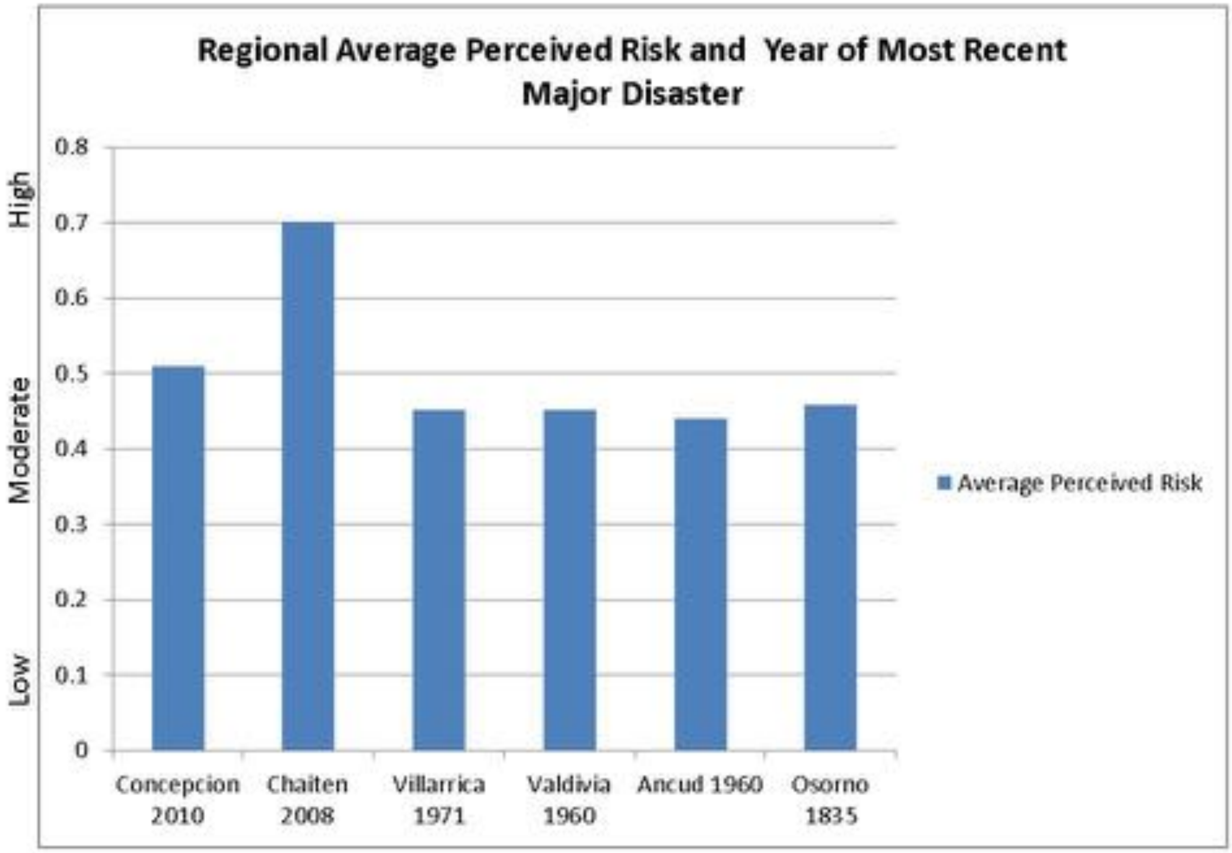


Figure 16: Perceived risk is higher in places that have experienced significant, damaging disasters in the past decade. Concepción and Chaitén have the highest perceived risk values, and the rest of the study area hovers in the moderate range. Correction: Osorno's last known eruption was in 1869.

Hypothesis 4: Individuals who have higher confidence in the government's capacity to respond to disasters are more likely to have taken fewer actions toward mitigation.

This supposition is contradictory in terms of overall community preparedness, because a well-prepared community generally has better-prepared individual residents. However, the results of this study indicate no significant correlations between preparation level and confidence in the emergency management branch of the government.

For this analysis, an accurate evaluation of confidence in the government is important. To achieve a confidence value that accurately captures respondents' confidence in the government, we asked them outright to rate their confidence on a scale of 1 to 3 (1 low, 3 high) in various levels of the government in their capacity to mitigate disasters. We then asked them to answer questions that painted a broader picture of their confidence in the government, such as questions about ONEMI's past performance and current actions of mitigation. The means between the outright response and the aggregate value are only slightly different.

	N	Mean	Std. Deviation	Std. Error Mean
AvgGovConfidence	133	1.9792	.55893	.04847
Aggregate Confidence in ONEMI	75	2.1067	.74568	.08610

Table 4: Average Confidence in the Government vs. Outright Confidence in Onemi. Both Variables have a 1-3 scale, with 1 being least confident and 3 being most confident.

Table 4 shows that the mean outright confidence in ONEMI (the emergency management department of the government) is slightly higher than the average of the aggregate-value confidence in ONEMI The mean outright confidence in ONEMI is 2.1, while the evaluated confidence level is 1.9, which is close to the value of 2 for moderate confidence.

The following table breaks down respondents' beliefs regarding the adequacy of governmental hazard mitigation efforts, such as the implementation of community emergency plans, alert dissemination, and adequate signage of tsunami or volcano evacuation routes.

The responses indicated here are in agree/disagree format, with "neither/nor" indicating a less severe degree of disagreement than "disagree." It is clear that the average adequacy rating of about 1.90 out of 3 means that respondents believe mitigation methods to be adequate (threshold of 1.50), but not excellent (3.0).

	N	Minimum	Maximum	Mean	Std. Deviation
Volcano Mitigation Methods	123	1	3	1.95	.848
Eq Mitigation Methods	131	1	3	1.87	.915
Tsunami Mitigation Methods	102	1	3	1.99	.838
Valid N (listwise)	95				

Table 5: "Are there sufficient hazard mitigation methods implemented in your area?" Respondents rated this question for volcano, earthquake, and tsunami mitigation methods, on a scale of 1-3 where 1 is strongly disagree, 2 is disagree somewhat, and 3 is strongly agree. The means show the average agreement level.

Tabulated Results

Comparison of Means: Confidence in Government, Disaster Experience, and Preparation Level

	N	Minimum	Maximum	Mean	Std. Deviation
Avg Confidence in Gov't	133	1.00	3.00	1.9792	.55893
Avg Aggregate Confidence in ONEMI	75	1.00	3.00	2.1067	.74568
Disaster Experience Level	135	.00	4.00	1.7630	.89948
Household Preparedness	133	.00	1.00	.6805	.24201
Have Felt Major Earthquake	134	.00	1.00	.8881	.31648
Have Seen Major Eruption	119	.00	1.00	.4538	.49996
Have Seen Major Tsunami	111	.00	1.00	.3153	.46675
Disaster Losses	136	.00	1.00	.2353	.42575
Emergency Plan Readiness	133	.00	1.00	.6667	.30151
Overall Preparedness Level	133	.00	1.00	.6736	.22943
Average Perceived Risk	135	.00	3.00	1.5938	.78216
Valid N (listwise)	67				

Table 6: This table shows that mean confidence in the government hovers around 2 out of 3, or moderate confidence. The Disaster Experience variable combines past earthquake, eruption, and tsunami experience, with dichotomous Disaster Losses responses (injuries, economic losses, deaths in the family, or injuries in the family). Here, Disaster Experience shows that the average degree of respondents' disaster experience is about 1.7 out of 4, which indicates low to moderate disaster experience. Most respondents (88%) have felt a major earthquake, which is attributable to the Concepción Earthquake. Fewer than half of the respondents have experienced a tsunami or volcanic eruption. Most indicate having emergancy plans, and the average overall disaster preparedness is about 67 out of 100. Finally, Average perceived risk is 1.59 out of 3, which corresponds with moderate perceived risk.

The table above shows that 88 percent of respondents have felt a major earthquake. Slightly fewer than half (45 percent) have seen a volcanic eruption, and 31 percent have seen a tsunami. This is a remarkable result, and it would be worthwhile to compare it with a similar population of people who have experienced earthquakes, tsunamis and eruptions in other countries. If given in the Pacific Northwest, the survey used for this study may indicate that some people have seen a major eruption (1980 Mount St. Helens), but that very few have seen an earthquake or a tsunami. The 2010 Concepción Earthquake was a significant event, the sixth largest recorded earthquake. It is highly likely that most, if not all, Chileans who were in Chile on that February day in 2010 felt that earthquake. That probability is reflected in the results.

The relationships between confidence in the government's hazard mitigation efforts, disaster experience, and risk perception help to illuminate what influences a person's perceived risk. Pearson's correlations run for confidence in the government and preparedness level do not indicate a significant relationship between the two variables (p-value 0.185 at the 0.05 level). This suggests that preparedness is not strongly influenced by confidence in the government's hazard mitigation capacity. Many respondents spoke of feeling obligated to take measures of their own rather than rely on the government for assistance in disasters. Residents of this study area seem to think that the government's efforts lack the clout to rigorously prepare for and respond to a disaster. This is particularly evident in Chaitén, where all respondents indicated ambivalence or negativity toward ONEMI's mitigation and response efforts in their area. Many *Chaiteninos* felt angry at the government for not coming to their aid in rebuilding the town after the eruption.

Tabulated Comparison of Means

Comparison of Means: Anxiety, Confidence, Preparedness, and Perceived Risk

	N	Minimum	Maximum	Mean	Std. Deviation
Age	135	12	79	36.89	16.041
Future Eq Anxiety	77	1.00	3.00	2.3247	.67749
Future Eruption Anxiety	79	1.00	3.00	1.9114	.87983
Future Tsunami Anxiety	69	1.00	3.00	2.1304	.82092
Avg Confidence in ONEMI	133	1.00	3.00	1.9792	.55893
Avg Confidence in Gov't	133	1.00	3.00	1.9792	.55893
Disaster Experience	135	.00	4.00	1.7630	.89948
Volcano Evac Required	129	0	1	.47	.501
Household Preparedness	133	.00	1.00	.6805	.24201
Disaster Losses	136	.00	1.00	.2353	.42575
Considered Moving	134	0	1	.09	.287
Emergency Plans Ready	133	.00	1.00	.6667	.30151
Overall Preparedness	133	.00	1.00	.6736	.22943
Average Perceived Risk	135	.00	3.00	1.5938	.78216
Sex (0=female, 1=male)	136	0	1	.51	.502
Years in House	105	1	75	16.76	17.083
Valid N (listwise)	61				

Table 10: The table above contains the study area-wide average values of disaster anxiety, confidence in government-implemented mitigation measures, disaster preparedness, and perceived risk, among other variables. The average anxiety, between 1 (low) and 3 (high) that an earthquake will happen in the respondents' lifetime is 2.3, or moderate to high anxiety. Respondents are slightly less anxious about tsunamis, and even less so about eruptions. Only twelve respondents have considered moving due to a nearby geologic hazard.

Respondents are fairly anxious about future earthquakes, tsunamis, and eruptions happening in their lifetimes. They have a moderately high level of confidence in the government to mitigate hazards, but if they were to be scored on a "disaster preparedness" exam out of 100, they would receive a 67 percent. Still, the average preparedness level suggests that more than half of the respondents have taken more than half of the indicated measures (have flashlight, fire extinguisher, first aid it, first aid knowledge, food saved, water saved), and have emergency plans ready (emergency plan readiness, evacuation route familiarity, and plans for electrical blackouts). This is a promising result, indicative of solid preparatory actions within households.

Comparison of Means: Disaster Anxiety and Expectation

	N	Minimum	Maximum	Mean	Std. Deviation
Average Disaster Anxiety Level	81	1.00	3.00	2.1276	.65260
Earthquake Expected in Lifetime	133	0	1	.92	.265
Eruption Expected in Lifetime	123	0	1	.76	.426
Disaster Expected in Lifetime	96	.00	1.00	.9583	.20088
Tsunami Expected in Lifetime	105	0	1	.82	.387
Valid N (listwise)	69				

Table 11: Not surprisingly, 92 percent of repsondents indicate that they expect another severe earthquake to occur during their lifetime. It is interesting that 76 percent believe that another significant eruption will happen during their lfietime, and 82 percent believe that a tsunami will happen. The average disaster anxiety, which takes into account earthquake, tsunami, and eruption expectance, is 2.1 out of 3, or moderately high.

It is clear that most of the respondents believe that another significant geohazard disaster will happen in their lifetime. This is not surprising, since Chileans have experienced a heightened frequency of disasters in the past six years, with the eruption of Chaitén, Llaima, and Cordón Caulle, and the Concepción Earthquake.

Overall, risk perception roughly aligns with geohazard risk in the study area, people with higher risk perception are more likely to have taken more disaster preparation measures, risk perception is higher in areas where disasters have occurred in the past decade, and preparedness is not strongly influenced by confidence in the government's ability to mitigate hazards.

IV. Discussion of Results and Global Implications of Geohazard Risk Perception in Chile

The results of this study indicate that most respondents perceive moderate to high seismic risk. This seems to be attributable to the fact that almost all respondents reported feeling the magnitude 8.8 Concepción earthquake in 2010. Chile is a seismically active country, and most respondents reflect that by reporting that they expect another large earthquake to happen in their lifetime. The average anxiety that another large earthquake will affect Chile and the individual respondent is about 6.75 on a 1-10 scale, which shows that the majority of respondents are at least moderately concerned about earthquakes happening in the future. Earthquakes can happen virtually anywhere in Chile and they are not as affected by topography or proximity to the hazard origin as are tsunamis and volcanoes. Their potential to happen without any warning signs makes them more unpredictable than volcanic eruptions and tsunamis, leading to a higher degree of uncertainty. High uncertainty and high degree of disaster experience, combined with the expectation that a major earthquake will happen again, yields a higher perception of risk.

High volcanic risk perception is limited almost entirely to areas where volcanoes are directly visible at close range to respondents. High volcanic risk perception is especially prevalent in Pucón, where the summit cone of Volcán Villarrica steams during the day and its summit crater casts an orange glow during the night due to the active lava lake inside. Volcanoes are hazards that are obvious to any onlooker. They can produce visible and sensible warning signs prior to erupting, such as bulges and tremors. It makes sense that, in areas like Pucón and Chaitén, where active volcanoes steam away close by, people have heightened perceptions of volcanic risk.

Tsunami risk perception is not as high as expected in coastal areas. This could be due to the fact that many respondents live in what they consider to be safe locations, above sea level. Tsunamis are unpredictable, but when an earthquake of any sort is felt near the coast, the municipalities emit a tsunami warning for at-risk zones, just in case the earthquake triggered a tsunami. Analysts who monitor the international tsunami-warning network then confirm that the earthquake generated a tsunami within several minutes of the initial seismic wave. However, since tsunami-producing earthquakes often occur at shallow depths in the subduction zone, their epicenters are only a few dozen kilometers out to sea, and a fast-moving tsunami wave could arrive before a definitive warning. Thus, coastal communities will sound tsunami-warning sirens even though they don't have a confirmed tsunami on the way. This ensures that a warning is emitted, even if it is not necessary. The survey did not include a question addressing how seriously tsunami warnings are taken, so we do not have an empirical notion of the effectiveness of tsunami warnings. However, many respondents, especially those living near the coast, were adamant about heeding tsunami warnings, reporting that they do it for nearly every earthquake. Our best estimate is that people living in tsunami hazard zones heed the warnings and evacuate to high ground.

Overall, perceived risk, actual risk exposure, and preparedness exhibit uniform characteristics across the study area. Most values for actual risk exposure and perception are in the moderate range, and preparedness levels only deviate from the average by small amounts. One of the more curious results is that the minimum and maximum risk exposure values are found in the two regions with the most recent disasters, Concepción and Chaitén. Risk perception is highest in these two towns, with Chaitén's perception value barely cresting the border between moderate and high risk perception. It is important to recognize that the actual risk exposure variable was computed using respondents' geographic proximity to hazards. The fact that a disaster happened in Concepción does not necessarily mean that its residents are exposed to risk, but tsunami inundation levels, such as the 8-meter example adopted from the Concepción-Talcahuano tsunami in 2010, can tell us a great deal about risk exposure. Few respondents in the Concepción area were located near the 8-meter tsunami inundation line.

A key factor that contributes to heightened perception of risk and preparation levels could be the increase in frequency of geohazard events since 2007. The eruptions of Llaima, Chaitén, and Cordón Caulle, along with the 2010 Concepción Earthquake, have raised geohazard awareness and understanding, if not increased the threat level people feel due to those hazards.

Perception and Preparedness Patterns in Coastal Regions

The magnitude 8.8 earthquake that struck Concepción and was felt throughout Chile on February 27th, 2010, is known in the vernacular as *El Veintisiete* (The 27th). The event was so powerful and so recent that almost any Chilean who was in the country on that day, and especially those in the central and southern regions, felt the earthquake. An internet search for videos of the earthquake provides a frightening glimpse of what it must be like to experience an earthquake of that magnitude, the sixth largest ever recorded. People shout to their family members and tell them to take cover amid the deep rumbling of the seismic waves and flashes of light from exploding transformers and gas lines. It is no surprise that most respondents across the study area reported feeling *El Veintisiete*, and it is clear that the earthquake had a significant impact on their risk perceptions and disaster preparation efforts.

Walking around Concepción and Talcahuano, you can still see relics of *El Veintisiete*: the vacant lot where the 10-story *Alto Río* building collapsed on its side; houses with windows and doorways slightly askew; an overturned ship in the waters off Talcahuano; areas under construction recovering from tsunami damage. We suspected that anxiety regarding tsunamis and earthquakes would be high in this area, since an event of such magnitude occurred just three years ago and since almost all respondents reported that they felt the earthquake on *El Veintisiete*. We used "earthquake anxiety" and "tsunami anxiety" variables in the analysis of Concepción and Talcahuano, because the more apt variables of "perceived seismic risk" and "perceived tsunami risk" had not yet been developed when these data were collected. The rest of the areas in the spatial analysis use the perceived risk variables, not the anxiety variables.

During our time in Concepción and Talcahuano, we visited sites such as the vacant lot that the Alto Río building once occupied, and the new government building constructed on skids that survived the earthquake with minimal damage. Every survey respondent except one reported that they experienced the earthquake. Based on reported tsunami and earthquake anxiety levels, respondents from this area have a lower-than-average anxiety toward earthquakes and a higher-than average anxiety toward tsunamis.

None of the respondents live within the 8-meter tsunami inundation zone, modeled after estimates of the impacts of a tsunami of moderate magnitude and based on inundation levels seen in Talcahuano (Koshimura et al. 2011; CITSU). Four respondents live close to the inundation zone, and their homes may be affected by a severe tsunami that results in inundation higher than eight meters. Talcahuano was hit hard by the tsunami on *El Veintisiete*. In total, thousands of people across the country were displaced and at least 525 were killed.[8]

In Corral and Niebla, the coastal hamlets associated with Valdivia, perception of tsunami and seismic risk is higher on average than in Valdivia. This is likely attributable to the proximity of these towns to the coastline. Some respondents are close to, if not inside, the tsunami inundation line. Low-resolution data impede exactness in determining inundation line proximity, but the respondents that live near the coast generally perceive higher tsunami risk in this region. Both towns have a strong fishing and logging presence in the region, each of which was disrupted due to the 1960 earthquake and tsunami. On the outside wall of a low-slung warehouse by the fishing harbor in Niebla, there is a mural depicting the town's history. About two thirds of the way through the montage, the artists painted a distressed fishing skiff being overcome by the tsunami wave as the

[8] *Informe final de fallecidos y desaparecidos por comuna*. Departamento del Interior, Gobierno de Chile. 2011

sentinel white dove flies through with a scroll with the words "Mayo 1960". To the right of that, a priest prays over several white crosses. Here, tsunamis have the potential to affect the residents very strongly, particularly the fishermen who spend much of their time on their boats and could lose their business if a boat sinks.

In Valdivia, only a few relics remain as reminders of what happened in 1960. A half-grounded ferry sits rusting among a forested bank in a quiet stretch of river. The concrete shells of abandoned buildings darken and crumble with the passing years under the rain. Giant cracks trace veins and arteries into old concrete and stone buildings. A few earthquake-themed bars and restaurants display photos of the destruction. Other than the occasional visual reminder, the people of Valdivia, young and old, seem to be very aware of what happened. Many of the older residents we surveyed were alive during the earthquake, and all of them remember it as if it had happened just hours ago. The legacy of the 1960 earthquake remains engrained in the memories of Valdivia's residents, even those who are too young to have experienced the quake. Given its history, it is somewhat surprising that Valdivia has a low-moderate average risk perception.

Perception and Preparedness Patterns in Volcano Regions

Overall, Chaiten exhibits the highest risk perception value, crossing the threshold into the "high" range. Villarrica and Chaiten have similar average risk perception levels, at the low end of the "moderate" range. It is not surprising that Chaiten has such a high perception level, due to the recent disaster there. Visual reminders of the 2008 eruption are everywhere, from homes half buried in volcanic mud deposits, to wreckages of buildings that were uprooted by the powerful debris-laden flood. Those who left Chaiten after the 2008 eruption may actually have the highest average risk perception level for the area, as they perceived high enough risk—or experienced such financial losses—that they were unable or unwilling to return to the town. This raises the interesting question of how the same respondents would have answered the questions on our survey prior to 2008. It is likely that their 2006 perception-exposure-preparedness profile would have looked more like that of Osorno, with low-moderate perceived risk and moderate preparedness. This implication suggests that disaster experience truly does influence perception of risk in a positive way. Recent disaster experience corresponds with higher perception of risk.

Many of the Villarrica area's residents are too young to have experienced the last major eruptions in 1964 and 1971, but they likely saw the minor eruption of 2011. The latter did not produce any damage, but the two former were very destructive in Lican-Ray and Conaripe. Surprisingly, Villarrica has one of the lowest average perceived risk values in the study area. The volcano steams away only ten kilometers away from some of the towns, and it is known as an active, dangerous volcano. The residents of the towns surrounding the volcano have confidence in the eruption detection and warning system, which may allow for a reduced perception of risk. They understand that the risk is there, but they don't necessarily feel threatened by it.

Overall, it seems like the town officials in Pucon are confident in the volcanic emergency response system. There are about 20 entities involved in the risk management and response network, including the response networks of the Chilean Red Cross, the Andean Rescue, the Carabineros, Firefighters, and various governmental and geological organizations that monitor Villarrica's activity.

One of the officials at the Pucon municipality made an interesting point about the region's volcanic risk. He said that even though Villarrica is the dominant figure in the town's volcanic emergency plan, there are even more dangerous volcanoes nearby, capable of violently explosive eruptions. This system is known as Caburgua-Huelemolle, and it has not erupted in over 6,000 years.[9] It is not likely to erupt, but the consequences of its eruption could be far greater than those on Villarrica.

[9] "Caburgua-Huelemolle" Smithsonian Global Volcanism Program

Although Osorno has a similar perception-exposure-preparedness profile to that of Villarrica, it is in a different volcanologic setting. Since Osorno has not erupted in almost 200 years, its neighboring residents have not seen an eruption from it. Calbuco, the volcano 35 kilometers to the southwest, last erupted in 1961, sending an ash cloud 15 kilometers into the atmosphere.[10] The high perceived volcanic risk observed in this region's respondents could be due to this eruption and its lasting memory instead of risk from Osorno.

Preparedness Patterns across the Study Area

Preparedness is nearly uniform across the study area, with the regional average preparedness in the "high-moderate" range for four of the six regions. The "moderate" value indicates that the respondent has taken over half of the household preparedness measures listed in the survey, including one emergency plan. The relative uniformity of this variable suggests that either a revision of methods is necessary to more accurately capture preparedness levels, or that the sampled populations actually present a high-moderate average preparedness level. The questions on the survey represent common actions people take regardless of being prepared for a geohazard disaster. Almost anyone is likely to have a flashlight and batteries, and many people are likely to have a fire extinguisher, food and water saved, and a first aid kit. The commonality of these measures may have skewed the regional average preparedness levels toward the high end. Perhaps focusing on the more telling preparedness measures—having a family emergency plan, knowing tsunami/volcano evacuation routes, and having a plan for electrical blackouts—would have yielded more wide-ranging results. However, the measures in the variables used for this study show that, on average, the sampled populations have taken at least one planning measure and have the majority of the household preparedness items in their homes.

[10] "Calbuco" Smithsonian Global Volcanism Program

Education plays an important role in disaster preparedness. Generally, education is thought to move perceptions toward accuracy and improve disaster preparedness (Palm 1981, Perry 1979, Wildavsky and Dake 1990). During our interview, Hugo Moreno noted that in Chile, natural sciences are woefully undervalued in the education system. The geologists that graduate from the best universities are wooed by high-paying mining jobs, and not enough devote their careers to seismology or volcanology. If more earth sciences students devoted their careers to hazard mitigation-oriented seismology and volcanology, perhaps risk understanding in Chile would improve, and risk perception would align more closely with actual risk exposure.

Global Implications

Geohazard disasters related to subduction zone activity happen all over the world in places with varying socioeconomic settings and capacities to deal with them. Chile, Indonesia, Alaska, the Philippines, Japan, and the Pacific Northwest have particularly active tectonic settings that produce earthquakes, tsunamis, and volcanic eruptions relatively frequently. The map in Figure 17 (below) shows the Ring of Fire, the seismically and volcanically active plate boundaries that border the Pacific Basin. Tectonics in these areas are responsible for the magnitude 9.6 Valdivia Earthquake of 1960, the 2004 Indian Ocean Earthquake and Tsunami, and the magnitude 9.2 1964 Alaskan Earthquake. Geohazard events generated at subduction zones tend to have high magnitudes and severe consequences. Places without proper infrastructure and social systems in place for dealing with these types of disasters are less resilient to their effects. Preparedness does not necessarily depend solely on having the economic capacity to mitigate hazards. In a place like Japan that is known for its seismic hazard mitigation efforts, events such as that of 2011 can push "beyond design basics" and overwhelm the mitigation measures in place. The tsunami in Japan overtopped the seawalls meant to stop it because the designers of the walls had not accounted for events as big as the 2011 one. Moreover, the Fukushima plant had been built to withstand a magnitude 8 earthquake, not the magnitude 9 that stuck on March 11, 2011. This shows that sometimes even the best preparedness efforts can fail, and that simply being prepared for a disaster does not guarantee resilience.

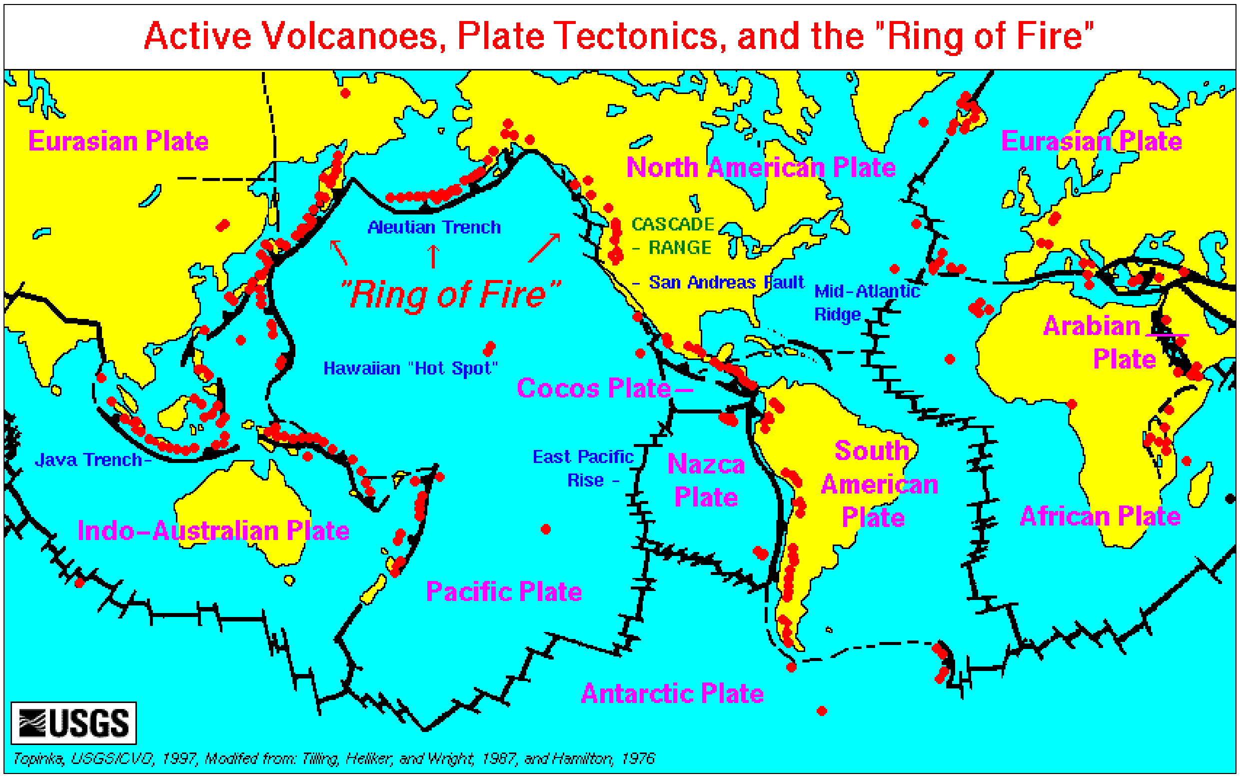


Figure 17: Global distribution of active volcanoes. Earthquakes can happen throughout the Ring of Fire and at most plate boundaries. Image courtesy of USGS.

The Great Cascadia Earthquake

Chile's subduction zone is very active. In subduction regions where few significant events have happened in the past century, it is likely that perception of risk is much lower than in areas with frequent disasters. Thus, in areas like the Pacific Northwest where large earthquakes, damaging tsunamis, and highly damaging volcanic eruptions have not happened recently, the kind of strong relationship between risk perception and disaster preparedness seen in Chile will not exist. It is clear that the Pacific Northwest is not as prepared for subduction-generated disasters as Chile is. Oregon is no exception. According to a 2013 report on the state's resilience to the future Cascadia Earthquake, "Oregon is far from resilient to the impacts of a great Cascadia earthquake and tsunami today."[11] This report indicates that fatalities could range from 1,250 to 10,000, with more than $30 billion in direct and indirect economic losses. This latter figure is close to one-fifth of Oregon's gross state product.[12]

A Cascadia Earthquake generated from the 600-mile-long fault called the Cascadia Subduction Zone could have a seismic moment magnitude ranging from 7.5-9.5, similar in severity to the 2010 and 1960 Chilean events. If Oregon is to be prepared for such an earthquake, it must undergo thorough and extensive assessments of the vulnerability of its buildings, infrastructures, and social systems. The goal of the Resilience Plan is to show how the state of Oregon can be more able to rebound from the earthquake, with stronger roads, buildings, and power infrastructure. The Oregon Legislature recognized the importance of disaster resilience for a Cascadia Earthquake when it passed House Resolution 3 in 2011, setting the stage for policy change. Since the possibility of a major earthquake striking the Northwest was recognized in 1984, the state has made an effort to build new buildings to withstand earthquakes. These efforts show a mild improvement in the state's resilience to earthquakes, but much more can—and should—be done.

If the survey used in this study on Chile were to be used in Oregon, it is likely that Oregon's risk perception and disaster preparedness would be in the "low" range. Few disasters besides the 1980 eruption of Mount Saint Helens have occurred in Oregon, so if patterns observed in Chile hold in Oregon, this low disaster experience would contribute to low perception of geohazard risk. And because perception and preparedness are so closely linked, it is likely that disaster preparedness for a Cascadia earthquake in Oregon would be very low. The Northwest has experienced a recent volcanic eruption—that of Mount Saint Helens

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[11] Oregon Seismic Safety Policy Advisory Commission, *The Oregon Resilience Plan: Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami,* Report to the 77th Legislative Assembly (Salem Oregon 2013).
[12] Ibid.

in 1980—but since the eruption occurred far from population centers and the number of fatalities was low, it is not seen as a cataclysmic natural disaster. However, if Mount Rainier were to erupt, it would likely destroy much of Tacoma and Seattle would be heavily impacted.

If a similar GIS-based geohazard risk exposure analysis were to be done in Oregon, the values would likely be similar or lower. I would rate current seismic risk in the Northwest as low, based on the 12 percent probability that a great Cascadia earthquake will happen within the next 100 years.[13] Risk perception would probably align with risk exposure levels to some degree, but risk exposure would tend to be higher than perceived risk, as it is in Chile. People in the Northwest may understand the risk of an earthquake to some degree, owing to a basic understanding of the region's geology, but they may not feel threatened by the possibility of an earthquake because they may have not experienced anything like it. This shows that disaster experience is often the link between understanding a risk and preparing for its effects. After experiencing a large earthquake, individuals may be more likely to feel threatened by future earthquakes, and thus more likely to prepare for them.

Conclusion

Since perceived risk aligns roughly with actual risk in south central Chile, it is possible that other places exposed to geohazards exhibit similar alignment. Risk perception stems from a multitude of sources: disaster experience, government-run hazard education programs, emergency simulations, and cultural familiarity with geohazard disasters. We can conclude that disaster preparedness depends in part on risk perception, but not on confidence in the government. Moving risk perception toward accuracy presents a difficult challenge, as it is relatively easy to increase understanding of risks, but not as easy to compel adaptive and preventative action

[13] USGS 2009 Earthquake Probability Mapping (Online Interactive Service)

and change behavior toward risk. Understanding how to change behavior toward risk may provide insights as to how to increase disaster preparedness where it is insufficient. Apart from experiencing a disaster firsthand, there may not be a way to truly understand the need to take preventative action ahead of time. Indeed, for risks of many kinds, the "probability threshold"—the probability of risk at which someone is more likely to take adaptive action—is so low that it is treated as zero, when the consequences of the risk are severe. In these cases risk must be re-evaluated and steps must be taken toward mitigation. This shows that there are limitations to educating people about hazards, and that experiencing a disaster firsthand may have more of a positive effect on household disaster preparedness efforts than not experiencing a disaster. Future similar studies could be conducted around the Pacific Rim to evaluate risk perception in places with different cultural and socioeconomic settings.

Geohazard risk mitigation is important in countries where related disasters occur frequently, such as Chile, and in places where time between events spans centuries. Understanding perceptions of risk can help us to better prepare for disasters by honing in on what causes people to act on information. Knowing why people perceive risk the way they do can help improve preparedness efforts and increase the resilience of populations worldwide.

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Appendix A: Survey Translated to English

Geohazard Survey (Version 4.1)

Hello! If you have time, we would like your assistance with a sociological-geographic survey for our university. It will only take 10 to 15 minutes of your time.

Brief Explanation: We are North American students at Lewis & Clark College in Portland, Oregon, and this is an official university project. We are interested in compiling information about how you perceive the geologic hazards around you. Geohazards are the objective hazards attributed to tectonic and geologic processes, especially with respect to seismic and volcanic activity. This survey has the following objectives: a.) to evaluate the capacity of the authorities (regional and local) in the effective mitigation of geohazards, and b.) to obtain a sketch of the perceptions of geohazard risk and vulnerability for the people in the VIII, IX, X and XI regions of Chile. **All of the information obtained in this survey will stay anonymous. If you require information about our study or the results of this project, please consult the information slip that we give you. Thanks for your time!**

Instructions: We are going to ask you a series of questions divided in 5 sections that pertain to distinct themes. The questions have the following formats: Multiple Choice, Short Answer, Agree/Disagree, Yes/No, and Scale of 1-10. **If you cannot, or do not wish to respond to a question because it doesn't pertain to your situation or for another reason, you may respond by writing "Not applicable" (N/A).**

Even though this survey and your responses are anonymous, we would like to have your permission to use some information about you, including your address, nationality, age, occupation and details about your family and household. If you prefer that we don't use any of this information, that's fine. But, it would help us a lot in the analysis of this information if you permit us to compile your information.

I permit the use of all of the personal information I provide: Yes__No__

Street Address:	**Nationality:**
Neighborhood or Commune:	**Age:**
City:	**Occupation:**

Date:	**Sex:**
GPS Waypoint (Researchers):	**Number of inhabitants in you household:**
Amount of time living in Chile:	**Amount of time living in your household:**

Section 1: General

1.1a) What was the last earthquake that you felt?

1.1b) What was the last tsunami that you've seen in your area?

1.1c) What was the last volcanic eruption that you have seen in person? (don't include eruptions that you've only seen in the news)

1.2) Choose all that applies. If nothing applies, leave it blank.
Have you had any personal losses (injuries, loss of family member, injury of family member, economic loss) due to:

	Injuries	Loss of Family Member	Injury of Family Member	Economic Loss
a.) a volcanic eruption?				
b.) an earthquake?				
c.) a tsunami?				

If you chose a loss, to which disaster is it attributed?

1.3) Do you live in a location where it is necessary to evacuate in the event of:

	Yes	No	N/A
a.) a volcanic eruption?			
b.) a tsunami?			

1.4) In your life, what was the most damaging geologic disaster?

1.5) In your opinion, which of the following events is the most damaging geologic disaster of the last century?

Valdivia Earthquake, May 1960		Eruption of Chaitén Volcano, 2008	
Valparaíso Earthquake, March 1985		Eruption of Llaima Volcano, Jan. 1, 2008	
Earthquake of February 27, 2010		Eruption of Cordón Caulle, 2011	
Eruption of Villarrica Volcano, 1971			

1.6) Have you considered moving due to any sort of geologic risk factor?

Yes	No	N/A

1.7) Have you and your neighbors taken precautionary measures against a disaster?

Yes	No	N/A

Section 2: Perceptions of Risk

2.1) What is the most dangerous volcano in your area?

2.2) Indicate the level of volcanic risk for the area where your household is located:

High	Moderate	Low	No Risk	N/A

2.3) Do you believe that an eruption of significant magnitude could happen during your life?

Yes	No	N/A

2.4) Please indicate the severity of the following volcanic risks for where you live. Respond from one to ten, where one is the least severe (or the risk doesn't exist) and ten is the most severe.

	1	2	3	4	5	6	7	8	9	10
Pyroclastic flow (a superheated cloud of gas and rock that travels at high velocity)										
Lahars (a flow of mud, rock and debris due to glacial melt)										
Ashfall										
Lava flow										
Noxious gases										

2.5) On a scale of one to ten, where one is the minimum of anxiety and ten is the maximum, indicate your level of anxiety with respect to the possibility of a devastating eruption affecting Chile in general.

1	2	3	4	5	6	7	8	9	10

...and in your area specifically.

1	2	3	4	5	6	7	8	9	10

2.6) Indicate the level of seismic risk for the area where you household is located:

High	Moderate	Low	No Risk	N/A

2.7) Do you believe that an earthquake of severe magnitude could occur during your life?

Yes	No	N/A

2.8) Please indicate the severity of the following seismologic risks for where you live. Respond with an answer between one and ten, where one is the least severe and ten is the most severe.

	1	2	3	4	5	6	7	8	9	10
Mass Movement provoked by shaking										
Falling buildings/structures/furniture due to shaking										
Fires, loss of water infrastructure, and/or other secondary effects of earthquakes										
Inundation due to the waves of a tsunami caused by an earthquake										

2.9) On a scale of one to ten, with one being the least anxiety and ten being the most anxiety, indicate your level of anxiety related to the possibility of a devastating earthquake affecting Chile in general.

1	2	3	4	5	6	7	8	9	10

...and in your area specifically.

1	2	3	4	5	6	7	8	9	10

2.10) Do you believe that there is an average amount of time between (major) volcanic eruptions?

Yes	No

If yes, how much time?

2.11) Do you believe that there is an average amount of time between big earthquakes?

Yes	No

If yes, how much time?

2.12) Indicate the level of inundation risk due to tsunamis for the area where your household is located:

High	Moderate	Low	No Risk	N/A

2.13) Do believe that a tsunami of significant magnitude could occur during your life?

Yes	No	N/A

2.14) Does your area have a previous history of inundation due to tsunamis?

Yes	No	N/A

2.15) Did you know that an earthquake on a distant coast, such as Peru or Japan, can also cause a tsunami on the coasts of Chile?

Yes	No	N/A

2.16) On a scale of one to ten, where one is the least anxiety and ten is the most anxiety, indicate your level of anxiety related to the possibility of a devastating tsunami affecting Chile in general.

1	2	3	4	5	6	7	8	9	10

...and your area specifically.

1	2	3	4	5	6	7	8	9	10

Section 3: Communal and Household Disaster Preparedness

3.1) Choosing from the following options, in which one(s) have you learned how to act during an earthquake?

Primary School		At Home	
Secondary School		In the Workplace	
High School		Other Location (Specify):	

3.2) Which of the following measures of security and preparation have you (or your family) taken to ensure the safety of your household in case of a geologic disaster or event? Indicate your answer with an "x".

	Yes	No
Have available a first aid kit with antiseptics to clean and disinfect wounds or burns		
Have available a fire extinguisher		

Have flashlights with extra batteries		
Have a basic knowledge of first aid		
Make an emergency plan with your nuclear family and have a meeting spot		
Have an amount of imperishable food saved		
Have an amount of water saved		
In the case of damage to the plumbing or electrical network, have a plan for what to do without gas or lights		

3.3) Please indicate which of the following methods of communication for alert emission would be most effective in informing you and your household.

Text Message	
Email	
Television Alert	
Radio Alert	
Emergency Sirens	

3.4) Are you familiar with the evacuation route and safe areas in case of a volcanic eruption or tsunami?

Yes	No	N/A

3.5) Your house is constructed using:

Wood	
Bricks/Adobe	
Concrete	
Antiseismic Methods	
N/A	

Section 4: The Authorities and Hazard Mitigation

4.1) Is it more important that the national government, your community, or both entities, take into account geologic hazards and prepare for them?

The National Government	My Community	Both

4.2) Please rate your confidence in the effectiveness of the following levels of government in responding to a geologic disaster:

	1	2	3	4	5	6	7	8	9	10
The National Government										
The Regional Offices of ONEMI										
The Municipality or Communal Government										

To answer the following questions, choose "I disagree", "I neither disagree nor agree", or "I agree", and explain your response if you wish.

4.3) The National Emergency Office (ONEMI) and the other federal organisations conducted themselves effectively after:

	I disagree	I agree	I neither disagree nor agree
The eruption of Chaitén Volcano in 2008			
The eruption of Llaima Volcano in 2008			
The earthquake and tsunami of February 27, 2010			

4.4) There are enough methods implemented to reduce the risks related to volcanoes where I live.

I disagree	I agree	I neither disagree nor agree

4.5) There are enough methods implemented to reduce the risks related to earthquakes where I live.

I disagree	I agree	I neither disagree nor agree

4.6) There are enough methods implemented to reduce the risks related to Tsunamis where I live.

I disagree	I agree	I neither disagree nor agree

4.7) There is a well-established alert system for volcanic eruptions in my area, and it works well.

I disagree	I agree	I neither disagree nor agree

4.8) There is a well-established alert system for tsunamis in my area, and it works well.

I disagree	I agree	I neither disagree nor agree

4.9) The signage implemented by ONEMI to indicate areas of high tsunami inundation risk works well.

I disagree	I agree	I neither disagree nor agree

4.10) The signage implemented by ONEMI to indicate areas of high volcanic risk works well.

I disagree	I agree	I neither disagree nor agree

End of Survey. Thank you!

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