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Paper:

Towards a Comparative Framework of Adaptive Planning and Anticipatory Action Regimes in Chile, Japan, and the US: An Exploration of Multiple Contexts Informing Tsunami Risk-Based Planning and Relocation

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Coastal regions around the Pacific Ring of Fire share the risk of massive earthquakes and tsunamis. Along with their own political-economic, cultural and biophysical contexts, each region has their own history and experiences of tsunami disasters. Coastal areas of Washington State in the U.S. are currently at risk of experiencing a tsunami following a massive Magnitude 9 (M9) earthquake anticipated in the Cascadia Subduction Zone (CSZ). Looking ahead to consider adaptive planning in advance of a tsunami following this M9 event, this paper explores how lessons from recent megaquake- and tsunami-related experiences of risk-based planning and relocation in coastal areas of Japan and Chile could inform anticipatory action in coastal Washington State. Based on a comparison of earthquake and tsunami hazards, social factors, and the roles of government, this paper outlines a framework to compare policy contexts of tsunami risk-based planning and relocation in three Ring of Fire countries, including factors shaping the possible transfer of approaches between them. Findings suggest some aspects of comparative significance and commonalities shared across coastal communities in the three countries and at the same time highlight numerous differences in governance and policies related to planning and relocation. Although there are limitations to the transferability of lessons in disaster adaptive planning and anticipatory action from one national/regional context to another, we believe there is much more that Washington and the Pacific Northwest can learn from Japanese and Chilean experiences. In any context, risk reduction policies and actions need to garner political support in order to be implemented. Additional case study research and detailed analysis is still needed to understand specific lessons that may be applied to detailed risk-based planning and relocation programs across these different national contexts.

Keywords: risk-based planning, earthquake, tsunami, disaster governance, residential relocation

1. Introduction

The science of tsunami hazards in subduction zones around the Pacific Rim of Fire has been the focus of extensive multilateral international scholarly exchanges of observation capacities, data, analysis approaches, and modeling for some years [1]. Research exchanges on comparative international policy and planning implications of this science have followed only more recently [2–5]. Scholarship that attempts to draw lessons from recent experiences of subduction megaquakes and tsunamis in countries within the Ring of Fire and apply them in the context of places that are threatened by yet without having experienced similar hazards in living memory is even more embryonic. As social science members of a recent combined geoscientific, engineering, planning and policy panel discussing precisely this problem [6], the authors here outline for likely the first time a framework to compare the policy contexts of tsunami risk-based planning and relocation in three Ring of Fire countries, and to consider what factors shape the possible transfer of approaches between them. This framework sheds light on the multiple political-economic, cultural and biophysical contexts in Chile, Japan and the United States that inform risk-based planning and relocation. It also affords insights into adaptive planning and anticipatory action regimes across these locations. To develop this framework, we identify the key aspects that shape the situations within the three countries and outline future comparative analysis of shared similar-

ities and contrasting conditions. To introduce this framework, we first describe the general context, then in Section 2 we compare the earthquake and tsunami hazards by country, in Section 3 the social context, and in Section 4 lay out our comparative framework, with reference to the roles of governments in anticipatory planning and post-tsunami relocation and recovery, and related focal activities and functions.

Coastal Washington State is at risk of experiencing a tsunami following a massive Magnitude 9 seismic event, anticipated from the Cascade Subduction Zone (CSZ) [7]. Linked on the Pacific Ring of Fire, coastal regions in Chile, Japan, and the U.S. Pacific Northwest states Washington, Oregon and northern California share a history and risk of experiencing future catastrophic earthquakes and tsunamis. Facing similar offshore subduction zones, Japan, Chile, and the U.S. have experienced major earthquakes and tsunamis, including the Great East Japan Earthquake (GEJE) and tsunami in Japan in 2011; the 1960 earthquake and tsunami in Chile that also reached Japan and the U.S., as well as the 2010 Maule earthquake and tsunami; and the 1700 earthquake and tsunami in the Pacific Northwest in the U.S. that generated a tsunami in Japan. Based on an analysis of the political-economic, cultural and biophysical contexts that shape tsunami risk-based planning and relocation in the three countries, this paper considers how experiences of adaptive planning and post-disaster relocation from Chile and Japan could inform approaches in coastal Washington and anticipatory action regimes in advance of a massive seismic event on the CSZ.

Although the three countries have a shared risk of massive earthquakes and tsunami risk, and coastal communities face similar challenges in dealing with recovery post-tsunami or in anticipation of a large earthquake and tsunami, a limited number of publications have considered these issues within an international comparative framework. Within the field of disaster studies, the need for more research on the recovery phase has been well-established, as has the lack of international comparisons [8, 9]. Drawing on the authors' knowledge of the respective pre- and post-disaster planning contexts in Japan, Chile, and the United States, this paper proposes an international comparative framework for anticipatory planning and post-tsunami relocation and recovery.

With the strong emphasis in Japan on risk-based planning and housing relocation projects on a massive scale after the 2011 GEJE, published research on recovery after the GEJE has focused on land use [10–12], processes of recovery planning and relocation [13–15], and housing policy [16, 17]. Multiple publications have focused on recovery after the Chile tsunami [18–22]; risk-based planning and recovery policy in the U.S. is also well studied [23–27]. Although the U.S. does not have recent experience with post-tsunami disaster recovery, other cases of disaster recovery have been well documented [28, 29]. A smaller number of publications have compared recovery experiences in multiple countries including Chile and Japan [4, 5, 30], and comparisons of U.S. and Japanese housing recovery policies are limited [31]. The authors are unaware of any published research that considers Chile, Japan, and the U.S. Along with the framework comparing these three countries, this research is also unique in considering how tsunami experiences in Chile and Japan could offer relevant lessons for coastal Washington in the U.S., an area that has not experienced a tsunami for several centuries.

2. Earthquakes and Tsunamis Experienced and Predicted in the Three Countries

Although they share the risks of earthquakes and tsunamis, Japan, Chile, and the U.S. each have their own disaster experiences. While Japan and Chile have experienced multiple tsunamis, as have the states of Alaska and Hawaii, Washington State on the west coast of the United States has not experienced a large tsunami for more than 300 years. On March 11, 2011, the northeastern Tohoku coast of Japan was struck by the GEJE and tsunami. This magnitude 9 earthquake caused a massive tsunami along the coast region of Tohoku, with a maximum height of more than 9.3 m in Souma City [32]. As of March 2020, the death toll was 19,729 with 2,559 people missing, and 121,996 completely destroyed houses [32]. Over the nine years since the GEJE, the number of evacuees decreased from 470,000 in the initial few days to 47,000 people still living in temporary or interim housing [32]. With regard to housing recovery for affected people, about 150,000 households have rebuilt or are in the process of rebuilding their own houses. Planned to be complete by March 2021, the national government's programs to support housing recovery include the preparation and provision of 18,000 new residential lots in high ground areas, as well as the construction and provision of 30,000 units of subsidized rental disaster recovery public housing.

Similar to Japan, Chile has extensive and repeated experience with seismic events; eight earthquakes with a magnitude Mw above 8.0 have occurred in the country since 1940. The largest was the Mw 9.5 disaster of Valdivia in 1960, followed by the 2010 earthquake in Maule (Mw 8.8); both of these temblors triggered large tsunamis that affected hundreds of kilometers of the country's coasts and resulted in significant human and material losses [19]. The death toll from the Valdivia tsunami was roughly 2,000, while hundreds of thousands were left homeless. The Maule earthquake and tsunami, in turn, caused around 500 deaths and left 190,000 dwellings uninhabitable. A total population of about 800,000 was materially affected. Following both catastrophes, the Chilean national government undertook intensive reconstruction plans, which nonetheless took years to complete [18, 20–22]. Reconstruction after the 2010 event was not completed until 2015.

In contrast, no major earthquake and tsunami has occurred along the CSZ in coastal Washington since 1700. The fact that this fault has been relatively dormant since then and that evidence for the 1700 quake was only dis-

covered recently [33] contributes to uncertainty in estimating the timing and magnitude of the next CSZ megaquake. The long-dormant fault system may mean that strain energy around the fault is building and therefore the risk of a megaquake may be increasing [34]. Alternatively, there is evidence of slow-slip behavior, self-healing slip pulses, and temporal and spatial clustering of events that complicate the relationship between "dormancy" and energy release – a topic of on-going debate [35–41].

Nevertheless, scientific knowledge of past CSZ events is rapidly evolving, as is the ability to model the impacts of future possible events. Probabilistic models based on patterns of recurrence revealed by inland and offshore geology suggest an estimated 17% likelihood that a Mw >9.0 earthquake all along the CSZ – the "maximum considered" for purposes of planning disaster preparedness and response – will occur within the next 50 years [41]. This kind of earthquake and the tsunami it would generate are expected to cause up to 10,000 direct fatalities in Washington and Oregon and more than $80 billion in economic losses [42]. The total population in California, Oregon and Washington living or working within the tsunami hazard zone for such an event is estimated at 137,296, but the majority are in Washington [43]. Vulnerability varies greatly depending on the local physical geography and demographic conditions; 48% of all residents exposed to tsunami hazards in the US Pacific Northwest are in the two Washington counties of Pacific and Grays Harbor, which have relatively large populations on long sand spits with no nearby high ground [43].

Earthquakes in each of these three countries also have impacts on the others. The 1700 CSZ earthquake generated an "orphan" tsunami in Japan. Historical records of this event were instrumental in advancing CSZ science [33]. The GEJE generated surges along the northern coast of California and caused $44 million in damages [44]. The Southern Chilean earthquake and tsunami of 1960 generated waves of over 10 m in New Zealand, Japan, Hawaii, and Russia [45]. As countries in the Pacific Ring of Fire not only share similar risks, they also share disaster experiences. Interconnected through the hazards they face; multiple national and local contexts shape the characteristics of response and approaches to recovery in each country.

3. Social Context in the Three Countries

The socio-economic contexts in Japan, Chile, and the U.S. directly shape the local exposure to hazard risks in each country, as well as national level policies and those specific to the regions considered for the case studies introduced in later sections. Across the three countries, some common aspects include coastal areas characterized by small communities with aging populations, and communities facing serious issues of social vulnerability. Although some aspects, such as economic vulnerability, are shared across the coastal areas of the three countries, other factors of social vulnerability, such as aging, depopulation, longevity of residence, property market values, and security of housing tenure have varied impacts in each area.

In Japan, which is facing a drastically declining national birthrate, the rate of aging and depopulation had already been accelerating in Tohoku before this region was devastated by the GEJE. While unlike Japan, Chile and the U.S. do not face the issues of an aging society at a national scale, their small coastal towns are experiencing similar issues related to aging, including in coastal communities in Washington that typically have high proportions of retirees. For example, in the town of Westport in Grays Harbor County the median age was 43.8 in 2017, compared to 38.3 for Washington State in 2018 [46, 47]. As in Japan, there are declining economic opportunities for young people in coastal towns in Chile and Washington, and coastal towns in all three regions rely on tourism and natural resource extraction, to varying but significant degrees.

Populations in coastal areas of both Chile and Washington experience significant social and income inequalities, including indigenous populations with lower incomes and poorer health conditions than the state or national average. Compared to Chile and the U.S., the degree of income disparity between residents in coastal areas of the Tohoku region and the rest of Japan is less severe, although many disaster survivors face difficult economic situations.

The economies of coastal communities in all three countries include a reliance on tourism activities. This may increase vulnerability for those working in the tourism sector, as their livelihoods can be severely impacted by disasters as well as long term impacts from delays of economy recovery. Large numbers of visitors unfamiliar with local hazards and emergency plans and protocols complicate disaster response measures. In addition, coastal relocation can be challenging for recovery of communities that rely on tourism near the ocean.

Facing shared factors of social and economic vulnerability, these coastal communities heavily rely on government policies and assistance for mitigation and recovery support pre- and post-disaster. As explained in more detail the following sections, policies related to disaster response and recovery are closely related to non-disaster policy contexts of social welfare in each country. In the case of coastal communities in Japan after the GEJE, recovery projects were fully funded by the national government, similar to national policies of social welfare, and supported by government funding for infrastructure and to dispatch experts to help with planning and project implementation. In Chile, the role and level of funding from the national government is not as strong, with a lack of professional expertise as well as financial resources at the local level, which is also similar to the non-disaster context of social welfare in the country. In the United States, where government policies pre- and post-disaster have a limited degree of investment in social welfare, focusing rather on the protection of private property, there

Table 1. Multi-level responsibility of government for social services and housing welfare.

	Gov. type	Social services	Housing welfare
JP	National gov.	Funded and shaped by national government. While needs are expected to grow in an aging society, human and financial resources may not suffice to provide services in the future.	Social welfare housing support exists; the national government provides public housing etc. NGO roles are small.
	Local gov.	Local governments administer and provide social services to residents; NGOs play a very small role.	Local government has some role in implementation, although policies are primarily decided at the national level.
Chile	National gov.	Provided by a mix of governmental services and private supplier (for those who can afford them).	The national government provides social housing through the granting of subsidies to families for purchasing a dwelling, according to their income level.
	Local gov.	Local municipalities channel resources delivered from the central government for health and education.	Recent small-scale efforts by municipalities to provide affordable rents for residents.
US	National gov.	Federal programs are administered by federal, tribal, state, county and local governments or NGOs.	The largest national housing subsidy is the mortgage interest deduction for homeowners. The federal government also provides government-backed insured loans to qualified homeowners and builders. US Department of Agriculture has a range of programs to assist construction of rural housing.
	Tribal, state and local governments and NGOs.	Tribal, state and local governments provide social services, primarily with federal funding, and sometimes in partnerships with NGOs. Most large cities and some counties have housing authorities responsible for public housing, but rural areas tend to lack public housing.	National assistance for renters such as Section 8 and home buyout program, is generally administered by local governments. Other housing assistance or rent control programs are funded and administered by local governments and NGOs.

References: [16, 17, 31, 48–52]

is a smaller commitment to government-led housing relocation compared to Japan and Chile. Relocation and buyout programs that do exist in the U.S. focus on areas that have experienced or are at risk of riverine flooding; there are fewer cases of coastal relocation, and without recent tsunami experience in the U.S. mainland even fewer relocation projects are related to tsunami risk. However, considering the older and lower-income communities in coastal Washington, other international cases suggest that stronger government investment in relocation projects is needed.

4. Roles of Government on Multiple Levels

4.1. Multi-Level Responsibility of Government for Social Services and Housing Welfare

The responsibilities for issues related to the provision of social services and housing welfare during non-disaster times are distributed across national, state and local governments in all three countries (**Table 1**). National governments develop and fund social service programs and local governments often become the direct providers of services to residents. The Japanese national government supports housing welfare by providing public housing, for example. The non-profit and philanthropic sectors have a small role in providing social services including housing welfare support in Japan. The national government of Chile also provides some support for homeowners, through subsidies for housing purchase, according to the income level of residents. The largest national housing subsidy in the United States is the mortgage interest deduction for homeowners [50]; there are also some programs for rental assistance [51]. In all three countries, social welfare and housing policies are primarily shaped and controlled at the national level, with various degrees of administrative control at the local level and/or participation of the private sector or NGOs at a smaller scale.

4.2. Responsibilities and General Approaches of Government for Mitigation and Recovery

The national governments in all three countries play a major role in forming disaster mitigation policy, and funding and implementation of mitigation and post-disaster reconstruction projects. Although degrees of control and decision-making ability vary, local governments also have an important role in implementing policies decided at the national level in all three countries. The various roles and responsibilities for disaster policies and projects at multiple levels of government are identified in **Table 2** [51–53]. In each case some issues have emerged regarding coordination between different levels of government, including cases where the national government does not take

Table 2. Responsibilities and general approaches of government for mitigation and recovery.

	Gov. type	Governance-general/overall	Disaster mitigation plans	Policies related to long term recovery
JP	National gov.	Funded and shaped by national government	Nationally-funded government subsidies were provided, but only to families in the lowest three income quintiles, covering around 49% of the affected families.	National (Japan) funding; policy creation. The national government created menu of recovery projects. Strong national guidance.
	Local gov.	Local government follows national government directives.	Local governments are responsible for sharing local hazard information and planning for evacuation and response.	The local government has the responsibility of making and carrying out recovery plans using the projects provided by national govt. Pressure to decide quickly in order to secure funding; lack of residents' consensus in decision-making; lack of taking the time to think.
Chile	National gov.	Civil protection in Chile is carried out by the National Emergency Office of Ministry of the Interior and Public Security (ONEMI). Its risk management strategy is ruled by the National Civil Protection Plan (2002).	The General Law for Building and Urbanism restricts land use on hazardous areas. There are also strong seismic-based structural design standards (including national-scale seismic zoning) to be followed.	Following the 2010 disaster, the Chilean Public Law 16282 (*Ley de Sismos y Catástrofes*) fast-tracked amendments to local planning schemes in damaged communities. These changes were guided by non-binding coastal reconstruction plans, usually not fully linked to existing local planning schemes, and lacking national guidance for this process. Subsides were granted for reconstruction.
	Local gov.	Typically, municipalities do not have risk-reduction offices. There is a lack of integrated coastal zone management to plan, regulate and manage the coastal border.	Local governments use local planning schemes to restrict land use in hazardous areas.	Reconstruction plans were made at the local level, supported by universities and private companies, without a strong role of government.
US	National gov.	National/local roles are loosely linked in a federal system that tends to favor state and local initiatives but can hinder large-scale mobilization and coordination.	FEMA (the Federal Emergency Management Agency) requires jurisdictions to write and adopt a Hazard Mitigation plan as a condition for receiving some types of non-emergency grant funding. FEMA will provide mitigation funding for worst-case ("maximum considered," 2500-year recurrence) tsunami and earthquake events.	There is a National Disaster Recovery Framework to coordinate across federal agencies and other parties involved in disaster recovery.
	Local gov.	Strong state and local autonomy in a federal system that limits national governance. Strong private property rights also limit state and local governments' ability to regulate land use and initiate development. Eminent domain allows government to expropriate private property (with compensation) but is rarely used to reduce hazard risks. Court cases are frequently used to resolve conflicts and determine liabilities.	Hazard Mitigation Plans (very loosely connected to land use planning) are generally implemented by a local emergency manager who often works in a public safety department and sometimes a city manager's or county office. The plans have little impact on land use regulation. Some tribes and non-tribal communities have climate adaptation plans with tools for coastal hazards risk management that could be adapted for tsunami risk as well.	Recovery plans are often designed and implemented on the level of individual states. Local governments have emergency preparedness and management responsibilities, which include disaster relief. However, long-term recovery pre-planning is rare, and its absence leads to *ad hoc* recovery.

References: [8, 10, 11, 20–22, 26, 51–56]

responsibility specifically for risk mitigation (Chile), or the opposite case where the national government controls the process and there is less authority to make decisions at the local level (Japan), and a general lack of coordination between the national and local levels (Chile and U.S.).

In each country there are challenges to respond at the local level. In Chile, this includes a lack of professional skills and monetary resources at the local level, and difficulties of mainstreaming risk into local-level planning schemes, which have the final say about local land-use. In Japan after the GEJE, local municipalities had the responsibility of making and carrying out recovery plans using the projects provided by national government; although they had the responsibility to make and implement the plans, they faced various pressures to follow the directions set by national government, and to decide quickly in order to secure funding, which limited the time and ability to do context-sensitive planning and include residents in decision-making in meaningful ways across the disaster-affected area. Local governments in the U.S. are responsible for emergency preparedness, management and disaster relief, though in federally-declared disaster zones the Federal Emergency Management Agency (FEMA) can directly administer relief. FEMA also provides funding through state-level emergency management agencies for local mitigation projects and planning according to federal standards. Long-term recovery pre-planning is rare, which leads to ad hoc recovery. The integration of hazard mitigation planning with local comprehensive land use planning and other instruments of development regulation is still relatively rare and embryonic in the U.S., though increasingly recognized as desirable [55, 56].

As shown in **Table 2**, varied responsibilities for different aspects of disaster mitigation, response and recovery planning processes exist at multiple levels of government in all three countries. These roles are related to a wide number of subjects, including policy making and funding provision, mitigation and land use control. Focusing on risk-based planning and relocation, the following subsections compare policies related to housing recovery, buyouts and relocation, and land use regulations in the three countries.

4.3. Buyouts and Relocation

Buyout programs to purchase property of disaster affected residents exist in all three countries, however approaches and scales at which buyout and relocation programs are implemented vary widely. In Japan, relocation programs are being implemented on a large scale and as a main component of the residential relocation which is in turn a primary part of post-tsunami recovery. In Chile there is little relocation – it was only applied intensively in two severely-devastated coastal communities, Constitución and Dichato. Constitución and Dichato have populations of about 52,000 and 4,000, respectively [18]. Roughly 61% and 66% of their urban areas were affected by the 2010 tsunami. During the reconstruction process, Dichato's touristic and fishing communities received direct government subsidies for reopening, while Constitución's small-scale entrepreneurs had to obtain personal loans for this same purpose of reopening their businesses. In both towns, as local planning schemes were not a subject of noticeable changes, authors warn about incipient gentrification processes, triggered by availability of well-located land, "protected" by recently-built civil engineered defenses against tsunamis and tidal waves [21, 22].

The case of coastal Washington is different as no major tsunami has occurred in living memory. Recognition of tsunami risk in Washington is less than three decades old, and active planning for it at the community level began only after 2000, spurred especially by the 2004 Indian Ocean and 2011 Tohoku events. Non-tribal coastal communities have been active in evacuation planning but have taken few steps to incentivize relocation from or discourage development in tsunami hazard areas. By contrast, most Native American tribes in the region are planning anticipatory (pre-disaster) relocation to higher land and are at various stages of implementing these plans. Most tribes on the outer coast have purchased or otherwise acquired land outside their reservations or cleared land outside of the risk area for development within their reservations, that would allow for relocation of tribal public facilities and for households to move out of tsunami hazard areas. The extent to which these initiatives are driven by tsunami risk, as opposed to other factors (such as households seeking more space to build homes), varies from tribe to tribe. Tribal relocation plans generally do not involve buyouts. Property rights-based and property-market-value(tax)-leveraged strategies are typically not viable for Tribes, whose land and housing is owned according to a complex mix of freehold titles registered with local counties or states and collectively and individually held federal trust lands. Tribes often do have access to a number of federal grant and financing programs for the construction of housing, public facilities and infrastructure, however. In the case of the Quileute Tribe in Washington, the federal government returned hundreds of acres of National Park Service land to the Tribe in 2012 which allowed them to move housing and services out of a tsunami hazard zone [57]. The Tribe's first goal was to move the tribal school to higher ground and they received $44.1 million in federal aid to do so [58].

In addition to the scale of the buyout programs, the processes and mechanisms to acquire land also vary between countries. In Japan, where large scale buyouts are occurring, these programs are part of a 2-step process that includes acquisition of previous residential lots, now designated "hazardous" land, and provision of new residential lots for sale or rent. While U.S. buyout programs have not been applied to deal yet with tsunami risks in the Pacific Northwest, they are applied widely to manage other kinds of risks, including coastal and riverine flooding and storm hazards. In the U.S., buyouts are voluntary and usually end at the acquisition of land, leaving residents on their own to find new homes. There are some current exceptions involving 3rd party actors supporting the relocation to new sites, and counties that have pro-

vided additional support for relocation in some instances, e.g., King County [59].

In Chile, relocation as a public intervention can only be implemented through expropriation (condemnation), and people have been typically unwilling to sell their property. Japanese policy rarely uses expropriation; programs such as buyouts for collective relocation rely on residents' volunteering to sell their land. In the case of holdouts, projects must go around these individual parcels. However, after 2011, with these areas designated as hazardous, future new construction for residential use was forbidden by law, so the economic advantage of keeping these parcels was minimal. In community-oriented decision-making processes, there may also be strong social pressures to "agree" and "come to a consensus." This is the case for relocation projects in Japan, which are supported by most community members. This may differ from the cases of Chile and the U.S. Informal cultural and social factors related to how communities form collective policies and accommodate their members' individual interests are important topics for continued exploration within the international comparative study of this topic.

4.4. Designation of Risk and Relocation

Between the three countries, the role of land use regulation in risk designation, and how this shapes recovery policy and impacts residents' lives and choices, varies greatly. In Chile, planning schemes identify tsunami flood zones as risk areas. Some (non-binding) reconstruction plans do not allow the construction of residential buildings or key infrastructure in tsunami floods zones. Others only use tsunami flood zones as a basis for designing evacuation strategies. There is also the inclusion of some "anti-tsunami" engineering solutions, such as public waterfront parks that serve to disperse or redirect tsunami wave energy. In Chile, each town (municipality) is entitled to develop its own risk-reduction measures, through their local planning schemes and emergency plans, following guidance by national-level laws and institutions. Large scale infrastructure and engineering solutions are still very scarce.

In the Tohoku area of Japan, post-tsunami recovery projects include land use controls, especially those that deal with residential relocation, and changing the allowable use in areas at risk from tsunami to allow commercial but not residential uses. These land use controls in Tohoku are combined with massive infrastructure and engineering projects that created physical tsunami projects such as levees, sea walls, hardened river levees, and raised highways and roads.

In the U.S. Pacific Northwest, the states of Washington and Oregon, and northern California, differ in how they use tsunami hazard maps and the designation of risk areas. Washington State has adopted a "worst case" scenario mapping approach for planning purposes that focuses on evacuation, including the design of vertical evacuation structures. Oregon also relies on the worst or most severe ("maximum considered") scenario for vertical and horizontal evacuation planning but has made a greater variety of probabilistic tsunami hazard scenario maps available to local communities for a variety of other purposes, including for potential application to land use regulations and relocation decisions (e.g., for relocation of residences or public facilities). Actual regulation and relocation based on tsunami risks has not yet been approved in either state, however.

4.5. Infrastructure vs. Environmental Management

To differing degrees, all three countries rely on post-disaster reconstruction projects that rebuild and/or strengthen pre-disaster infrastructure. However, in the U.S., flooding and storm events are followed increasingly by projects that avoid rebuilding housing and infrastructure in vulnerable locations and instead take the opportunity to restore flood-prone areas' ecological function [60].

In Japan after the GEJE, large scale engineering projects have been a major focus of recovery, with the construction of huge levees and sea walls, mountain top removal, and massive modification of landscapes and townscapes, in the process destroying not only natural habitats, but also views of the sea. Recovery projects are not required to engage in rigorous environmental impact assessment.

In Chile, reconstruction plans also include public infrastructure (water, sewage, electricity, etc.) provided as part of a laissez faire policy within a neoliberal development model; all the companies that provide these services are privately-owned, although they must meet the standards and requirements established by the authority. As their focus is on making profit, they therefore tend to minimize the quality and coverage of their networks, including during the reconstruction process.

While there has been a lack of protection of critical areas (e.g., wetlands), this may be changing [20]. After the 2010 tsunami, during the reconstruction processes of towns like Constitución, Dichato and Pelluhue, new open areas have been developed on former residential land. However, this has been for mitigation and recreational purposes, not necessarily focused on restoring ecological functions.

In the U.S. Pacific Northwest, no major tsunami has occurred to require reconstruction, but the implementation of some pre-disaster anticipatory mitigation projects to reduce risk have begun. The Army Corps of Engineers is undertaking a major shoreline restoration project with the Shoalwater Bay Tribe and neighboring communities, which have the fastest-eroding beach on the U.S. west coast. While this project is focused on evacuation planning rather than adaptive planning or relocation for tsunami hazard mitigation, it represents the capacity of federal and local partnerships to undertake major coastal ecological engineering projects in this region. These communities have also built the first tsunami vertical evacuation structure in North America, at the nearby Ocosta School, which was funded entirely from local property taxes. Other vertical evacuation facilities, including at Shoalwater Bay, are now being constructed or planned with local and FEMA funding.

5. Conclusion

This paper has presented a brief overview of the hazards history and social and policy contexts that inform anticipatory planning and post-tsunami relocation in Japan, Chile and the U.S., with a focus on comparing across countries the roles and responsibilities of governments in planning and recovery. Findings suggest some aspects of comparative significance among three countries that have experienced or are facing tsunami hazards on the Pacific Rim of Fire, demonstrate commonalities shared across coastal communities in the three countries, and at the same time highlight numerous differences in governance and policies related to planning and relocation. In all three countries the national government provides at least a framework for mitigation and recovery, but implementation falls to some extent on local governments; coordination across levels of government appears to be a weak link. The national government in Japan appears to have a stronger central role, however, than does the Chilean national government, or even the U.S. government. The strength of formal legal institutions relative to informal societal practices is also stronger in both Japan and the U.S. than in Chile.

Considering these and other broad societal differences, there are many limitations to the transferability of lessons in disaster adaptive planning and anticipatory action from one national/regional context to another. Still, our motivation in building a comparative framework included being able to transfer some lessons – especially from those regions where numerous and recent subduction megaquake and tsunami disasters have occurred (Japan and Chile) to a region where such disasters are likely but rare and have not occurred within living memory or written history (Washington State). The science of tsunami hazards in subduction zones has rapidly advanced in recent decades, to the point of being able to articulate how these three regions are unified by their shared tectonic condition around the Pacific Rim, as well as their differences based on place-specific geology. Tsunami events in Japan and Chile have informed models of possible future events in Washington. Those models have in turn informed anticipatory decisions in Washington to invest in vertical evacuation structures and community relocation. Popular support for these investments has also surely been inspired by dramatic news coverage of recent devastating tsunamis in the Indian Ocean in 2004 and in Japan in 2011.

Based on our comparative survey, we believe there is much more that Washington and the Pacific Northwest can learn from Japanese and Chilean experience, despite the differences in context. In any context, risk reduction policies and actions need to garner political support in order to be implemented. In general, strategies to reduce risks from rare hazards – even existentially threatening ones – need to serve multiple purposes, and be seen as beneficial regardless whether and when a disastrous event occurs. The U.S. is currently characterized by relatively strong state and local governmental autonomy, limited public assistance for social welfare, and heavy reliance on private property markets and regulation (as opposed to direct public investment) to determine the location and types of housing, infrastructure and other land uses. All these factors would suggest that Japan's nationally-driven investments in levees, sea walls and other major tsunami risk-reducing infrastructure that compromises coastal ecological functions, would not be feasible in the U.S., especially on Washington's sparsely populated coast, where forestry, fisheries, shellfish harvesting, and outdoor recreational tourism are the bedrock of coastal economies.

Sea level rise and other impacts of climate change, however, also threaten this economy. Therefore strategies that adapt to these threats *as well as* to tsunami hazards may be more politically feasible. Such strategies may include at least partial community relocation, or retreat from threatened shorelines, if economic benefits can be gained from them, or if insurance costs can be reduced. The replacement of tsunami-damaged shorelines with open space in Chile might inspire similar, anticipatory treatments on the Washington coast that also function as sea level rise buffers where the health and extent of shellfish beds and fisheries "pay" for such investments. With greater awareness of tsunami hazards, the improved life safety that vertical evacuation structures provide a community might also translate into higher property values and reduced insurance costs.

Japan's experience with community relocation often involves private-property-based land readjustment [61], which has applicability in other contexts [62, 63]. Some combination of insurance adjustments, buyouts, transfer of development rights (TDR), and land readjustment could be feasible for purposes of community relocation in the U.S. Further combining these policy tools with subsidies for affordable housing to low-income households might add to the feasibility of relocation out of hazard areas, or of providing additional settlement areas in safe sites to which residents could relocate if their land were lost due to a tsunami. U.S. federal assistance to tribes proves the feasibility of this concept. Although their direct federal treaty arrangements make tribes distinctive, a recognition of the need for investment in resilient, sustainable rural development more generally might lead to support for non-tribal communities as well – especially those with high rates of housing insecurity and employment precarity, given the public health costs and the dependence that coastal economies have on the seasonal labor associated with these conditions.

More extensive research, based on case studies as well as more detailed analysis of institutional and cultural differences, will be needed to understand what lessons may be learned and applied to detailed risk-based planning and relocation programs across these different national contexts. The science of tsunami hazards are developing rapidly in all these contexts and increasingly involve the sharing of data and model-building expertise. The desire to know how this science may be applied in local contexts is becoming more urgent, suggesting an increasing need for comparative research on tsunami risk preparedness,

planning and mitigation. Regardless of national context, important indicators of successful application of disaster science in planning and risk assessment include: (1) increasing social inclusivity in decision-making, (2) reducing wealth and power disparities, and (3) increasing the regime's capacity to respond to new, probabilistic, and uncertain disaster information with (4) creative, robust, and locally-appropriate policies, programs and environmental/structural designs.

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