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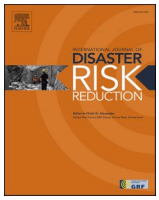

Scientific controversy as a disaster risk factor: The 2007 seismic crisis in Patagonia, Chile

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ABSTRACT

In 2007, a sequence of geophysical events occurred in Chilean Patagonia that manifested themselves in a series of earthquakes and a fjord tsunami, causing many months of disruption to the normal functioning of a region not known for seismic activity. Panic and uncertainty spread throughout the population and calls were made for an effective response and implementation of risk management plans. The geophysical events sparked a management crisis and subsequent socio-political conflict with mass demonstrations.

The present study explores this territorial conflict and seeks to identify institutional practices connected to disaster risk in Chile. Centralism, a lack of trust in the authorities, scant availability to the community of scientific information about local geo-hazards, and territorial heterogeneity are among the structural elements identified.

This conflict was explained by the various public actors in charge of the response as the consequence of a scientific controversy. We therefore question the links between knowledge production and dissemination. The study approaches the phenomenon from the point of view of the 'experts' – that is, those in possession of technical knowledge – before studying the handling of information and associated uncertainty. An analysis of the discourses and interventions on the part of public, scientific and technical figures, authorities, media outlets, official reports, communities and local residents confirms that information about disaster risk, communication of same, and the scientific communication were risk factors.

From this case study, we argue in favour of changes in scientific knowledge governance and integration of local knowledge for effective disaster risk reduction.

1. Introduction

As a contribution to academic efforts to reduce disasters risk, and in view of the need to transcend disciplinary boundaries, the present article offers an interdisciplinary analysis of a relatively recent natural disaster in order to advance new points of reflection on the institutional mechanisms related with disaster risk in Chile.

The work deals with the seismic crisis that took place between late 2006 and mid-2007 in the vicinity of the town of Puerto Aysén in Patagonia, where a sequence of thousands of earthquakes and a tsunami in the nearby fjord caused the deaths of ten people. The event caused severe disruption to daily life, provoking fear, uncertainty and panic in a region with little experience of seismic events. Inhabitants were forthright in their reaction, demanding the formulation of response plans and effective emergency management measures.

However, the diversity and improvised nature of interventions, implemented as they were by a large number of different actors at the national, regional and local level, yielded fragmented, confused and at times contradictory action which fostered social unrest and intensified the perceived risk. The geophysical event sparked a management disaster that in turn developed into a sociopolitical crisis that saw demonstrations, the waving of black flags,[1] and public disorder in response to the actions of the central government.

The social crisis is considered to be an expression of processes that

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[1] In Chile, the waving of black flags is a symbol of extreme discontent among the citizenry, alluding to mourning and a feeling of strong discontentment with political authority.

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had been in motion since before the geophysical event struck and, as such, reveals the underlying factors that led to unrest [1]. We therefore view the case as an opportunity to observe and identify processes and behaviours that may explain the critical triggers of a risk situation, and how issues of institutionality constitute a risk factor in themselves. From this analysis, we expect to query links between scientific production and risk production often taken for granted in disaster risk reduction literature and policy guidelines.

The present article has six parts. To begin, section 1 consists of the current introduction and section 2 presents the methodology used in the study. In section 3, a state-of-the-art and theoretical aspects of the 2007 Aysén crisis are presented, undertaking a review of studies that have addressed this crisis and assess their contributions and limitations to understanding the production of risk in this case. In section 4, the phenomenon is explored from the point of view of the experts – in other words, from the technical angle – in order to help understand the treatment of information and associated uncertainty, in a scientific controversy context. Finally, we discuss what is needed in order for science to be able to make a valuable contribution to the reduction of risk (section 5) and present some conclusions.

Beyond its exploration of the case study, the present work seeks to reflect on the restrictions to participation faced by Chilean scientists in issues of national interest such as disaster risk, and to contribute to the development of a means by which science and academia may participate more constructively in dealing with the large-scale social challenges of today.

2. Methodology

The researchers involved in the current study come from diverse disciplines: civil engineering, public law, social geography and seismology. The team developed three methodological complementary processes:

1. The analysis of the crisis started with a state-of-the-art review of the event and more broadly of disaster crisis case studies, presented on section 3.

Additionally, our study includes data and information collected by fieldwork and interviews carried out by our institution shortly after Aysen crisis occurred [2], which served to define our methodology. Previous publications based on interviews, focus groups or testimonies of key actors and local inhabitants were used as secondary sources of information in Sections 3 and 4 [3–5].

2. A systematic data recompilation was established in order to trace the production and circulation of technical and scientific information. Aysén case's comprehensive review included scientific papers as well as national and international technical offices reports (Chilean National Emergency Office, ONEMI; Chilean National Geology and Mining Service, SERNAGEOMIN; National Seismological Service, SSN; Controller General of the Republic; Regional office of the Ministry of Health; Pan American Health Organization, PAHO) and corporate reports (Salmon aquaculture report), from 2007 to 2015.

This was complemented with an exhaustive press review using regional newspapers (El Divisadero, El Diario de Aysén) and major national newspaper (El Mercurio), based in Santiago. The review period was from January to May 2007, from digital online archives and Chilean National Library physical collection.

Each intervention of the 'experts' or mention to a geophysical diagnosis was systematized in a table describing: event date, author (person or institution) responsible of the information, synthesis of the diagnosis, complete diagnosis, acknowledged sources, media features.

From the prior analysis, a detailed narrative analysis of experts' positions on the controversial argument of the phenomenon origin was conducted, presented on section 4.

3. A quantitative analysis of research funds on topics related with the crisis was finally carried on, presented on section 4.

The principal source of finance for scientific research in Chile is the public sector, and this is coordinated by the National Commission for Scientific and Technological Research (CONICYT), part of the Ministry of Education. CONICYT offers many types of competitive grant, including the National Fund for Scientific and Technological Development (FONDECYT), the Fund for the Promotion of Scientific and Technological Development (FONDEF), and the Fund for Research Centres of Excellence in Priority Areas (FONDAP). Other important financing agents include the Ministry of Economy, Development and Tourism, which offers competitive funds for the creation of Millennium Science Initiative (ICM) centres; and the Economic Development Agency (CORFO), which provides funding for projects relating specifically to economic productivity. All these funds were considered in the study.

We therefore conducted an analysis of scientific production relating to disaster risk in Aysén which received finance from the main national science funding bodies. We sought to assess the relevance – in terms of number of studies funded – of the issue of disasters according to national scientific priorities, as well as the accessibility of the results of these studies and the origin of the researchers and research centres. The decision was made to cover a period beginning and ending ten years before and after the emergency. This time frame was chosen to match other national studies of risk, such as the assessment and quantification of the seismic risk associated with the San Ramón Fault in the Metropolitan Region of Santiago, which involves complex scientific problems of an interdisciplinary nature. Some of the funding bodies identified could only be reviewed as far as 2014 due to the availability of accounting records.

For each institution, a detailed analysis of all projects funded from 1997 to 2014 allowed us identify projects concerning Patagonia region, relating to disaster risk, or concerning disaster risk in Patagonia region. Each project was then systematized in terms of the following categories: project Id, years, annual and total funding, institution, institution location, discipline or sector of activities, type of results and their accessibility.

3. State-of-the-art and theoretical aspects of the 2007 Aysen crisis

3.1. Patagonia, a frontier territory

Aysén, in Chilean Patagonia, is the third largest of Chile's regions, covering an area of 110,000 km^2; however, it has the lowest population density and the fewest road and digital connections. Its limited demographic, economic and political weight has made the region highly dependent upon decisions and resources from the central government [6]. That said, the region has, since 2000, experienced a degree of economic dynamism as a result of a move towards more productive sectors, namely salmon farming, the mining of gold and zinc, forestry, and tourism [7].

Since the 20th century, the Aysén region has been presented as peripheral – a frontier space which transcends its physical condition and exacerbates its limited political and administrative integration into the national territory. This explains the construction over time of *territorial imaginaries*: various historical processes have transformed the region into a *discursive frontier* whose sociocultural relations are shaped by both state and local agents to create a redefined territory that is remote, exceptional, and lacking in progress, often viewed simply as a life and nature reserve [8,9].

As a result of its location in the Andean tectonic subduction zone, Chile is one of the most earthquake-prone countries on Earth, with an average of at least one earthquake of magnitude 8 or higher per decade

and two main tectonic regimes. The *North-Central Zone*, where the oceanic Nazca plate is subducted below the South American plate at a rate of 8–9 cm per year, runs from the country's northernmost point to the Taitao peninsula (46°S). The *South Zone* features two triple junctions at which the South American, Antarctic and Nazca plates, and the South American, Antarctic and Scotia plates, respectively, interact. Aysén is situated in a zone of diffuse and slow deformation that generates a significantly lower rate of seismic activity than that of the rest of the country, but the region's tectonic complexity is far greater. Between 38°S and 48°r the zone between Liquiñe in the Los Lagos region and the Gulf of Penas in the Aysén region, lies a geological fault system known as the Liquiñe-Ofqui Fault which is connected with the region's volcanic activity. Prior to 2007 no seismic activity had been registered along the Liquiñe-Ofqui Fault, due partly to the lack of interest in the region on the part of specialists and the resulting lack of permanent seismic monitoring, and partly because no events had been identified as directly linked with the fault system based on the seismic data available.

3.2. The 2007 Aysén crisis

January to May 2007, Aysén fjord, Aysén Region: In the area surrounding the towns of Puerto Aysén and Puerto Chacabuco, thousands of low-to medium-intensity near-surface earthquakes occurred at an average rate of 66 per day.

The main seismic event in the sequence took place on 21 April 2007 at 13:43. An earthquake of Mw 6.2 with epicentre on Mentirosa Island in the Aysén fjord triggered around 300 mass movements [10]. The sudden fall of three of these large masses of earth into the Aysén fjord produced a tsunami which expanded in a series of waves with maximum heights estimated at 15 m and a horizontal penetration of up to 50 m in Puerto Aysén.

The tsunami caused major damage, including the death or disappearance of 10 people (most of them salmon workers and local residents), the destruction of two homes and serious damage to another 230, destruction of three electricity posts, interruption to water and electricity supplies for several hours in areas close to the epicentre, partial collapse of the Presidente Ibáñez bridge over the Aysén river (essential road access to the town), damage to salmon farms estimated at US$ 10 million at the time [2], and a mass escape of between 1.5 and 5 million salmon, the largest cage escape worldwide, the environmental repercussions of which are as yet undetermined [11,12]. The earthquakes required the evacuation of 50 people, provoked temporary and permanent migration, and generated psychological problems among the population, manifested in an increase in the number of emergency consultations [5]. Fig. 2 presents the chain of events of Aysén crisis.

3.3. Disaster and disaster risks

In the wake of the devastation caused by the earthquake and tsunami of 2010, Chile has been undergoing a gradual shift in its understanding of risk and socio-natural disasters, moving the focus from an emergency-based *civil protection* approach towards appreciation of the cyclical nature of risk and the resulting need for *disaster risk management* [65]. This has yielded a number of initiatives, including the implementation of new protocols on the part of institutions responsible for emergency response, the creation in 2012 of a new National Seismological Centre, a drive to comply with international commitments laid out in the Hyogo Framework for Action 2005–2015 and the Sendai Framework 2015–2030,[2] ongoing parliamentary discussion of a reform to the National Emergency Office [13],[3] and the permanent inclusion of the issue in the national scientific agenda.[4]

In support and motivation of these decisions, the world of academia has produced studies aimed at contributing to knowledge of threats and vulnerabilities, identifying major failures evident in past cases, and developing new tools to improve disaster risk management proficiency. Unfortunately, despite considerable academic efforts, many of these works have been conducted from within a distinctly separate set of disciplines, and dialogue between them has lacked the required fluency [14].

However, both academia and public policy have made advances in recent decades in terms of adopting an integrated approach to disaster risk, and the focus of responsibility for the impact of the event has been expanded to include not only the natural hazard itself, but all of the physical, social and political factors that contribute to the threat, thus acknowledging that disasters are the product of interaction between both natural and social elements [15–17]. This new approach to risk brings together by definition a variety of scientific disciplines to interact and collaborate in the construction of knowledge [18–20], leading to new research perspectives such as the link between informality and disaster risk construction [21–23], the role of land planning and urban design consideration in risk production [24,25], multivariate approach incorporating physical, environmental, and social indicators [26–28], risk perception [29,30].

Since the past decade, in particular since the 2011 Tohoku earthquake in Japan, risk governance literature has payed a renewed attention to multi-hazard and multi-risk events, and cascading effects of complex natural-social-technical assemblages [31]. There is a gap between multi-risk knowledge, with scientific tools such as multi-risk indexes and metrics, cascade scenarios or coupled systems' assessments, and risk reduction practices and gobernance [32]. Even though there is high interest of risk reduction practitionners in multi-risk assessments, applications are hampered by the difficulty of understanding hazard interactions [33] and by the complexity of processes involved [34]. Other barriers identified are closely related with the multi and interdisciplinary nature of risk reduction -lack of standard terminology, deficiency in expertise in the broad range of relevant disciplines-, or with governance challenges -inadequate resources, communication issues between stakeholders- [35]. Detailed studies of specific cascading events from a multi-risk governance perspective are still rare and are necessary to improve risk reduction systems.

The 2007 Aysén crisis has been the object of numerous studies covering a diversity of issues such as the historical seismology of the region [36,37], the earthquake swarm phenomenon [38–40], the process that generates a fjord tsunami [41–43], mass movement triggered by the earthquake swarm [3,10,44,45], the zone's tectonic faults and structures [46–48], the geological processes identified in the Aysén fjord [49], volcanism in the region [48], the environmental consequences of the mass escape of farmed salmon caused by the tsunami [11], management of the crisis [2], and the associated risk to agriculture [50].

All of these studies have contributed to the construction of

[2] For example, through the creation in 2012 of the National Platform for Disaster Risk Reduction led by the National Emergency Office (ONEMI), the creation in 2014 of the National Disaster Risk Management Policy, and the approval in 2016 of the National Strategic Disaster Risk Management Plan.

[3] Bulletin 7550-06. Bill which "Establishes the National Emergency and Civil Protection System and creates the National Civil Protection Agency".

[4] Funding was approved in 2012 for a FONDAP Research Centre for the priority area of "Natural Disasters": the National Research Centre for Integrated Natural Disaster Management (CIGIDEN). In 2014, a presidential mandate placed "Resilience against Disasters of Natural Origin" as a priority for the National Council of Innovation for Development (CNID), an entity created alongside the Natural Disasters Commission whose objective was to discuss a National Research, Development and Innovation Strategy for Resilience against Disasters of Natural Origin (CREDEN). It was decided that this strategy would be used as the basis for the creation of a Public Technology Institute dedicated to research, development and innovation for Resilience against Disasters of Natural Origin (ITRenD).

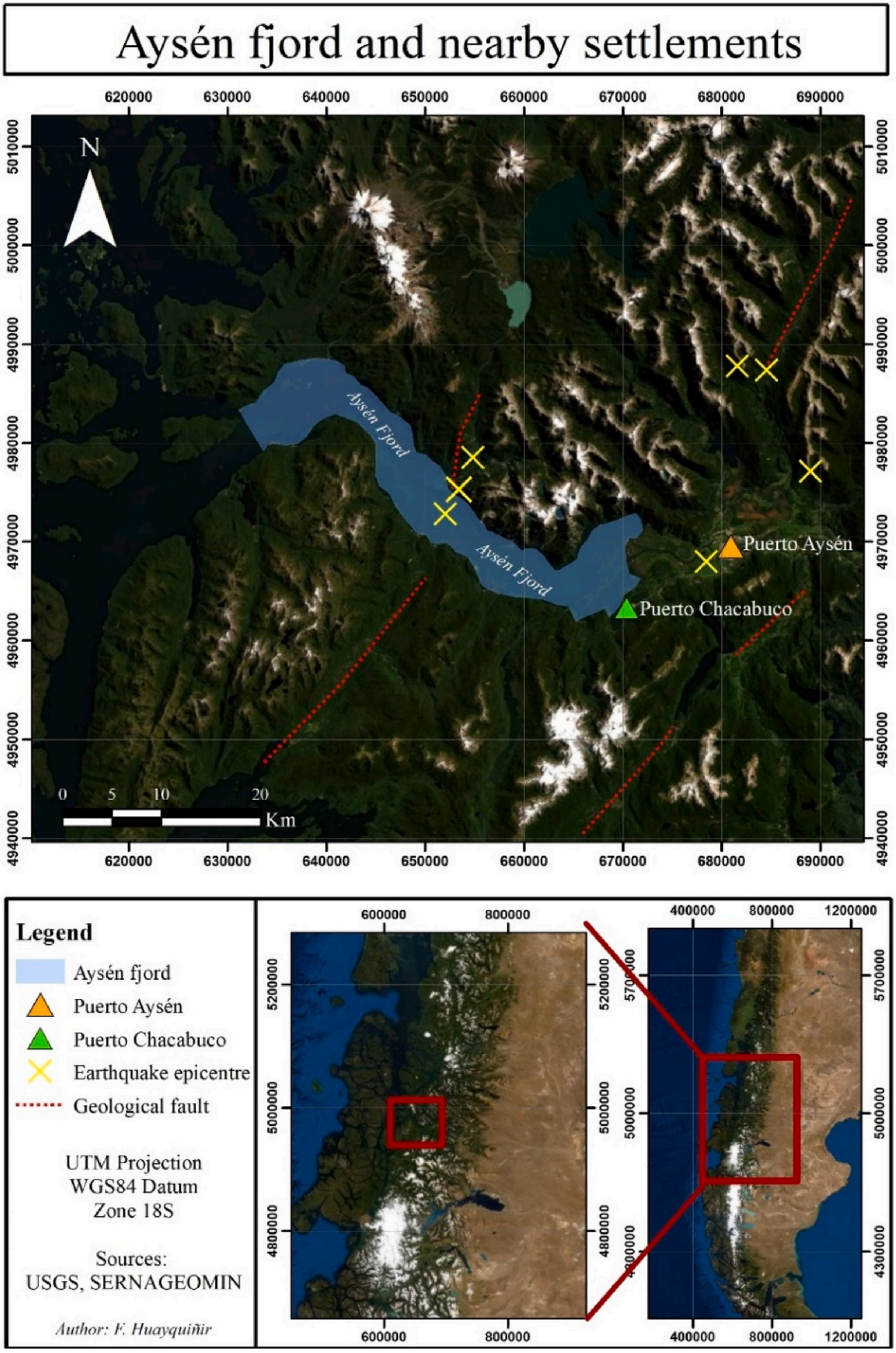

Fig. 1. Spatial context of the Aysén fjord and the main epicentres of the 2007 earthquake sequence.

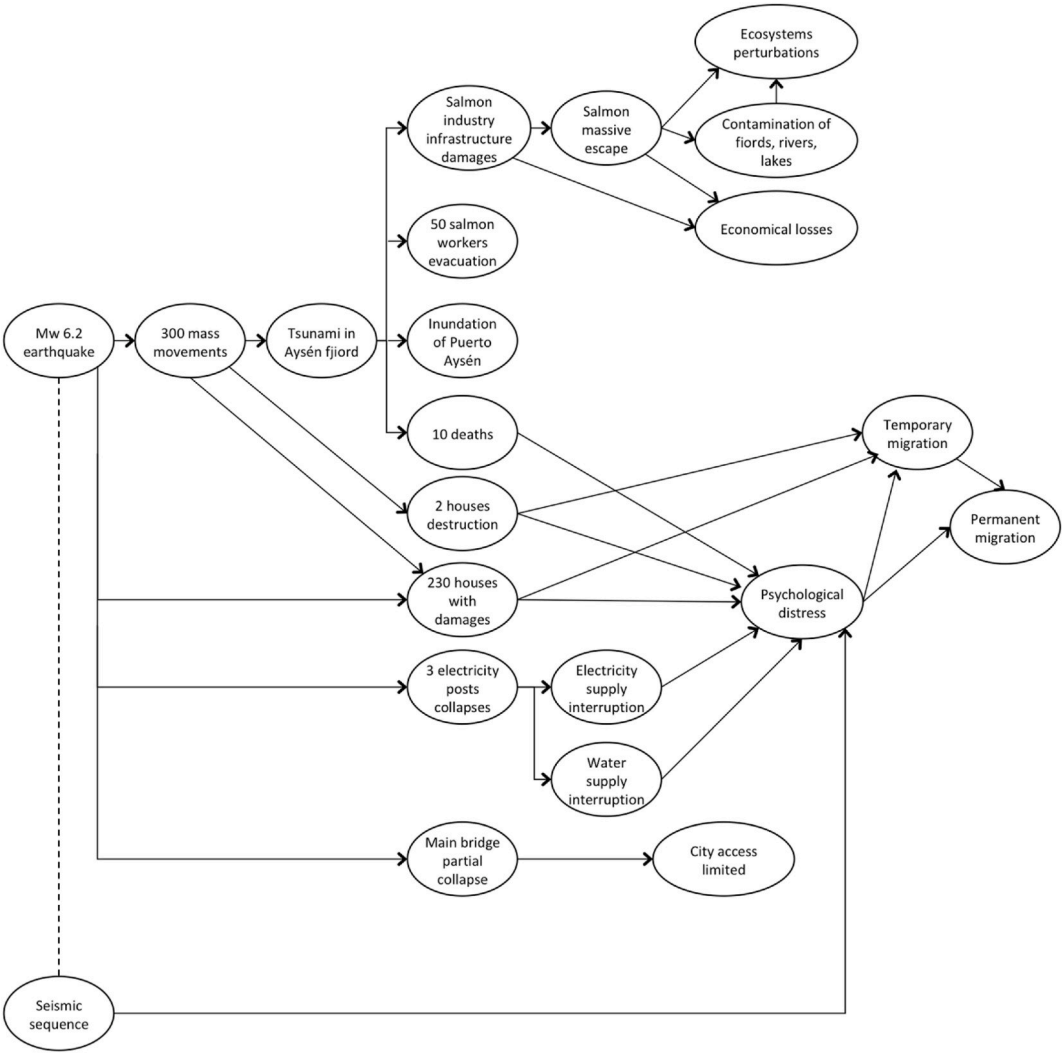

Fig. 2. Aysén crisis causality chain.

knowledge about risk in Aysén, particularly regarding the geophysical phenomenon and its impacts. The present article seeks to complement these by adopting a different approach in the search for new means of disaster risk reduction. As such, we propose to explore the notion of *governance* in terms of the idea of *territoriality* or, in other words, in terms of the diverse relationships that communities and individuals have with their spatial and temporal surroundings: with their territories.

3.4. A crisis of governance that reveals recurrent risk factors

The purpose of this study of the Aysén crisis is to explore the way in which risk and frequent crises are produced in Chile, particularly in terms of disaster-related risk. As D. Desroches reflects:

> "The urgency lies not in the crisis but in the human catastrophe that may follow. Emergency does not exist in the cyclical view of time: it is the result of a linear view. (…) Crisis may be understood as the short time frame of the decision that constitutes a point of no return, a critical moment of choice (…). Once the crisis has taken place, the catastrophe may emerge as the materialisation of the improbable. (…) The moment of the catastrophe makes the consequences of the crisis felt: it is a stifling moment in linear time which is 'of no time', as it is a past to which there is no possibility of return."[5]

Management of and response to the 2007 Aysén crisis reveals a lack of anticipation and preparedness not only on the part of the authorities, but across the whole emergency system, characterised by a reactive approach involving improvisation and fraught with avoidable organisational errors. An example of this was the lack of a protocol for naming the Scientific Committee, leading to the appointment of experts based on decision makers' personal connections. This gave rise to questions as to the legitimacy of these scientists and their technical advice, and was evidence of the inability of the consultant scientific committee to operate appropriately and independently of external pressures or personal interests [4]. The lack of organisational foresight is linked to administrative inconsistency and the lack of clarity regarding the responsibilities and authority of the various actors. This resulted in a feeling that the crisis was being manipulated on different political and

[5] DESROCHES, Dominic. GESTIÓN DEL RIESGO Y ACELERACIÓN DEL TIEMPO. pp. 52–53 In: INNERARITY, Daniel & SOLANA, Javier. LA HUMANIDAD AMENAZADA: Gobernar los riesgos globales. Editorial Paidós. 1st Edition [63]. Madrid. Spain.

administrative levels in order to achieve certain private objectives, in the implementation of a fragmented and often contradictory set of initiatives – for example, the simultaneous set-up of two Emergency Committees under the control of political figures from different areas – and in clearly visible tension [2]. The cacophony of information that reached the population was due in part to the absence of any policy designed and implemented in advance regarding communications from the various actors in charge, particularly experts, as well as the treatment of information by local media, who favoured a sensationalist approach to more prudent reporting founded on science [2,4].

Fig. 3 presents Chilean administration structure and main legal frameworks, from national to local scales as it was in 2007 during Aysén crisis.

The crisis of governance stemmed also from the lack of confidence in the institutions in charge of handling the response, in particular the National Emergency Office (ONEMI) and the National Geology and Mining Service (SERNAGEOMIN) following failures in forecasting and mitigation of the eruption of Mount Hudson in 1991 [2,5]. This was evidently related to the lack of accountability and action on the part of public institutions, and the lack of transparency with regard to personal and institutional responsibility [51]. Trust in institutions is central to effective risk governance, especially when perception of risk is considered to be an underlying factor of said trust [5].

Failure to properly identify the natural hazards and physical and social vulnerabilities of the zone in advance, along with the lack of hard-wearing instrumentation to monitor these hazards, meant that the background necessary for a timely scientific assessment of the phenomenon was not available. Prior to 2007, the region was considered neither by its inhabitants nor by the authorities to be an earthquake prone zone, although the 1991 eruption of Mount Hudson had made the volcanic nature of the area clear. As the Aysén crisis unfolded, various geophysical scenarios were in existence simultaneously, but this controversial dimension of the scientific assessment was not taken into consideration by decision makers. The state of affairs was perceived by the population as a lack of competence on the part of the authorities [2,4]. This underlines the technical and conceptual difficulty posed by uncertainty when it comes to decision making and comprehension of what is taking place.

The territorial heterogeneity of Chile is an aspect that institutional disaster risk management fails to take into account. One effect of this is that the country's seismic building code (Norma NCh 433. Of. 96. de Diseño Sísmico de Edificios) only considers the threat presented by the subduction earthquakes that occur in the North-Central zone of the country. Cortical (or surface) earthquakes that occur in seismically active geological faults – as in the case of Aysén – are not accounted for. Fjord tsunamis are also not referenced in the standard, meaning that their definition and associated risk prevention does not come under the responsibility of any defined institution. The organism responsible for estimation and monitoring of the tsunami threat in Chile is the Naval Hydrographic and Oceanographic Service (SHOA) through the National Tsunami Early Warning System (SNAM). Its purpose is to monitor tsunamis in the open ocean using a network of tide gauges installed along the coastline and buoys dotted around the Pacific Ocean. The organisation's expertise and measurement systems do not, however, stretch to estimation of tsunami threats in fjords, lakes or other bodies of water.

A final point is the predominance of the national over the local, of the centre over the periphery, of regulations over experiences. In 2007, ONEMI had no regional offices, personnel or resources. The Aysén crisis was a hard lesson for the organisation which, by the end of the same year, had set up offices outside the capital [64]. However, Chile's strong degree of centralisation causes major problems and is embodied in particular by the figure of the 'Presidential Delegate'.[6] In general terms, this is a representative of the central government named by Supreme Decree of the President of the Republic – and occasionally with the approval of ministers – to coordinate action and efforts in the event of an emergency or catastrophe situation, and to spearhead any other 'urgent' public policy to which he or she is assigned. However, according to the Office of the Comptroller General of the Republic, the role of this figure is consultative rather than executive and has no attributes other than those granted by the decree that names the individual. This means that the position is purely symbolic, but at the same time it creates friction in the relationship with the regional, municipal and even ministerial teams usually responsible for disaster risk management. The Presidential Delegate has become a feature of major disasters since the Tocopilla earthquake of 2007.

To this may be added a lack of unity between centralised State administration and local municipal administration due to the fact that, legally, the two are completely separate, independent and unbound by standards of coordination, as presented in Fig. 3. This is another factor that severely inhibits the correct functioning of disaster risk mitigation at all levels.[7]

Scientific centrality was not the exception: the advisory scientific committee during the crisis constituted exclusively Santiago-based institutions. Information and attempts at management on the part of the local population and other players were heavily side-lined in all decision making, and were considered no more than background noise which need not be considered as formal expert information [2]. The sense of loss of control on the part of citizens and of the trivialisation of the situation by the national authorities generated both demand for solutions and a rejection of a centralised and technocratic risk management approach that excluded the people.

Given the complexity and interrelation of the underlying risk factors, we will now address the issue of the production and use of information with regard to risk and uncertainty. In order to do so, we will adopt a critical approach towards processes of knowledge construction.

4. The phenomenon as viewed by the experts: A controversial seismic sequence and fjord tsunami

> "If we start saying that the way we explained the scientific analysis to the public was lacking, then tomorrow we will have to start

[6] The assignment of Presidential Delegates generally takes place according to the following legal instruments: articles 24, 32 No. 6 and 35 of the Constitution; Constitutional Organic Law No. 18,575 of the General Principles of State Administration; and where applicable: Supreme Decree No. 104 of 1977 which contains a rewording of the text of Title I of Law 16,282 of 1965 which sets out permanent provisions in the event of earthquakes or catastrophes; the Public Sector Budgets Law for the year in question; the Supreme Decree which declares a catastrophe zone; and Resolution 1600 of the Office of the Comptroller General of the Republic.

[7] The State Administration is regulated by Constitutional Organic Law No. 18,575 of the General Principles of State Administration, a legal body which, in Article 21, subsection 2, exempts Municipalities (district councils) from compliance. The latter are instead regulated by Constitutional Organic Law No. 18,695 of Municipalities which grants exclusive authority to govern and act separately and independently from the Central Administration.

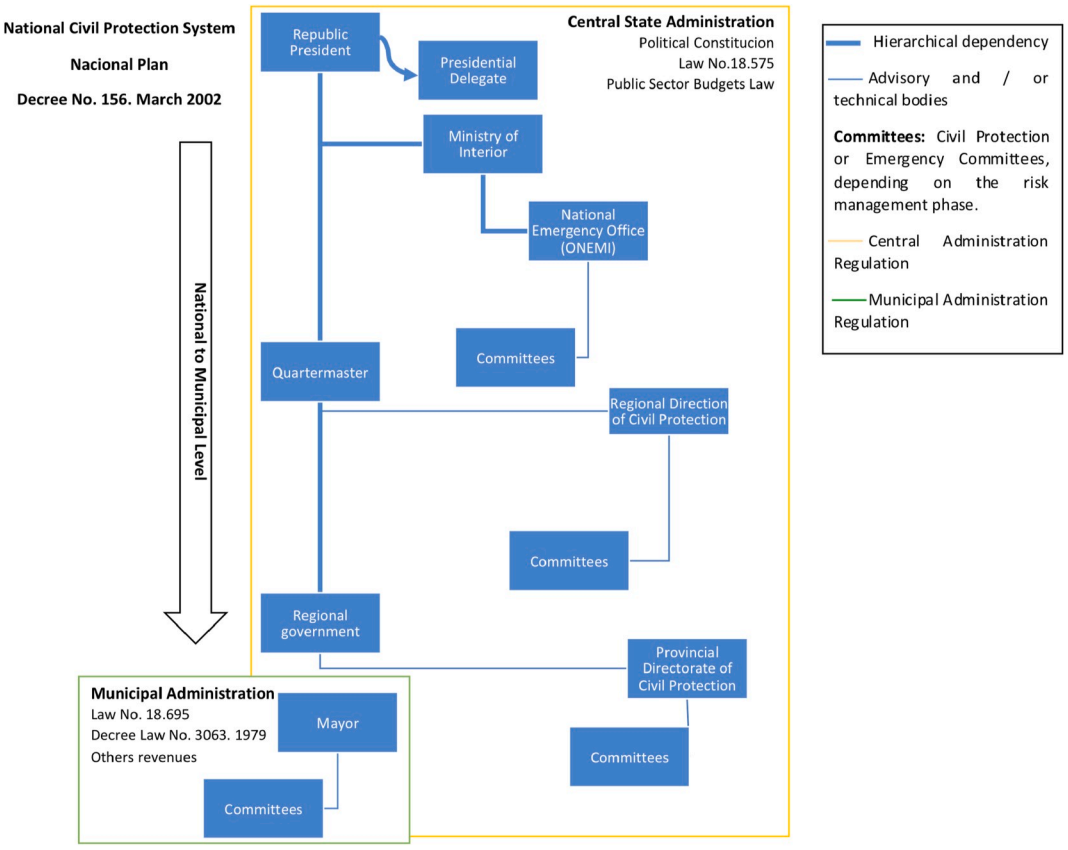

Fig. 3. Chilean Central and Local Administrations dependencies and regulations.

demanding that the medical world explain exactly which artery they cut and how they did the bypass."[8]

Carmen Fernández, Director, ONEMI (National Emergency Office), April 2007.

"A tsunami can only happen in Chile as a result of a high-magnitude earthquake in the subduction zone which, in the case of our country, is in the open ocean"[9]

Andrés Enríquez, Director of Oceanography, Naval Hydrographic and Oceanographic Service (SHOA), January 2007.

"They've never given precise information because they don't know; even they don't know. They're just standing around guessing."[10]

Mirta, Resident of Puerto Aysén, June 2007.

4.1. A scientific controversy

The need for information about the geophysical event that could support decision making during the response phase was quickly hindered by starkly differing diagnoses of the phenomenon. Divergent and contradictory hypotheses emerged as to the cause of the seismic event, which occurred along a 20–30 km section of the Liquiñe-Ofqui Fault that features many volcanoes, including one in the Aysén fjord. Assessment was hampered by the lack of ongoing monitoring and therefore of seismic data recorded prior to the sequence, the classification of the zone as non-seismic, the large number of experts called together in response, and the unusual nature of the event itself.

During the early days of the crisis, ONEMI put together a Scientific Technical Committee[11] to supply decision makers with scientific information. The committee's primary tasks were to diagnose and monitor the threat, and to contribute to the risk assessment and design of response measures [2]. Members of the committee were the official experts, and their main hypotheses were as follows:

(a) **Earthquakes as a result of the volcanic activity of Mount Hudson.** Despite being quickly discounted by all of the scientists consulted,[12] this remained the opinion of local residents until the end of the crisis [5].
(b) **Earthquakes as a result of submarine volcanic activity.** At the end of January, two possible scenarios were proposed, and this

[8] "Carmen Fernández: Analizaron traducciones ciudadanas y no los informes científicos" (Carmen Fernández: They analysed reports created for public broadcast, not the scientific reports). El Mercurio, Santiago, Chile, 25 April 2007. C6.

[9] "No habrá tsunami en Aisén, el origen sismológico está al interior" (A tsunami will not hit Aysén; the epicentre is inland). El Mercurio, Santiago, Chile, 30 January 2007. A9.

[10] "Informe final. Estudio de percepción social de la comunidad de Puerto Chacabuco y de Puerto Aysén respecto a las características de la situación de emergencia sísmica" (Final report. Study of the perceptions of the communities of Puerto Chacabuco and Puerto Aysén regarding the nature of the seismic emergency situation). Osorio et al. Coyhaique, Chile, June 2007. p. 26.

[11] Initially consisting of SERNAGEOMIN and the University of Chile's National Seismological Service (SSN). The University of Concepción and SHOA were added later.

[12] It was ruled out on 31 January in the first official technical report and press conference held by the Scientific Committee and the Aysén Regional Government.

was the one which gained the greatest consensus among experts. According to the hypothesis, seismic activity was induced by the injection of magma into the area's fault system which could lead to mild superficial seismic activity but would not affect coastal settlements.

(c) **Earthquakes as a result of tectonic activity in the Liquiñe-Ofqui Fault zone.** The second explanation was maintained by fewer experts and pointed to tectonic activity as the source of the earthquakes. This scenario would produce greater superficial seismic activity and a higher risk of mass movements.

(d) **Earthquakes as a result of a complex, mixed-origin tectonic/volcanic phenomenon.** This hypothesis proposed that only a combination of tectonic and volcanic activity could explain the complexity of the phenomenon.[13]

Alongside these official expert voices, other technical and political actors put forward counter-explanations or gave their support to some of those detailed above [2,4,5].

The result was a scientific and technical controversy that directly affected management of the risk and illustrated dysfunctional communication between scientists, technical experts, the authorities and the people. Although the controversy was a result of uncertainty surrounding such a complex phenomenon, there were other factors relating to the expert information which contributed to unrest.

Fig. 4 presents a timeline of the controversy surrounding the Aysén crisis and includes statements made by scientists, technical experts and political and administrative figures. The contradictions, confusion and sheer number of discourses from multiple actors is illustrated by quotations representing the positions of different parties. Categorical statements which nevertheless were subsequently refuted are shown in red; statements that considered different possible risk scenarios, including the tectonic hypothesis that was later confirmed, are shown in yellow; and statements supporting the tectonic hypothesis are shown in green. Given their strong relation to the discourses surrounding the crisis, the geophysical events themselves have been included (earthquakes, landslides and the fjord tsunami) along with the management measures implemented (formation of the Scientific Technical Committee, official reports, evacuation measures, etc.).

Modernity is accompanied by the new authority of the sciences, and particularly of the scientific method, which is established as a privileged means of understanding reality. In its normal modality [52], science produces knowledge from a recognised scientific community within validated academic spaces by means of peer approval criteria, publication requirements, and experimental protocols that ensure replicability. Normal scientific production times (of around ten years for Chilean geophysical studies) differ wildly from the duration of actual events (a couple of months, in the case of the 2007 Aysén earthquake sequence).

During the 2007 Aysén earthquake sequence, the sudden and urgent demand for information that would guide the design of crisis management measures pressured scientific and technical experts into proposing hypotheses within the short time frame of two weeks – in time for the first Scientific Technical Committee report – in a region in which research and monitoring prior to the event were almost non-existent. These hypotheses were, from the outset, built on major uncertainty, based neither on scientific precedent nor on validated data.

The scientific controversy was resolved through argumentation based on experimental data towards the end of 2007. Seismic and volcanic monitoring confirmed that the earthquakes were caused by the tectonic activation of the Liquiñe-Ofqui Fault system, thus enabling the other hypotheses to be discounted. In subsequent years, the phenomenon has been the object of a variety of geophysical and geological studies that confirmed this conclusion.

4.2. Post-normal science: the crisis of trust and legitimacy in Aysén

The unusual nature of the study surrounding the 2007 earthquake crisis in Aysén may be ascribed to the uncertainty of information and other factors, disagreement over values, high risks, and an urgent need for decision making; in short, the features of a post-normal approach to science [53]. Since the 1960s, sociological and philosophical critical reflection on scientific and expert processes have defined ways in which to 'do science', and this includes the technoscience conducted by private companies in order to generate patentable knowledge [54].

Similarly, diagnosis of the Aysén 2007 event comes under the definition of *regulatory science* [55], which is responsible for providing a basis upon which decision making may take place. These two processes and purposes are representative of trends over the past decade toward generation of scientific knowledge in response to disaster situations. Perhaps the most interesting case is that of the seismologists convicted of manslaughter through negligence following the 2009 earthquake in L'Aquila, Italy, due to the lack of certainty of their diagnoses.[14]

In Aysén, the lack of certainty and variety of possible scenarios was not taken into consideration in the handling of the response, and the focus of attention on the part of the authorities, the community and the experts was put on a single diagnosis. The possibility of a tsunami in the fjord, a theory put forward by a number of experts from within and outside the Scientific Technical Committee was omitted entirely from contingency plans. Furthermore, the hypothesis most widely agreed upon was accepted, and the others were rejected. This resulted in the formulation of contingency plans that in fact amplified the risk presented by those hazards that had been ruled out. For example, the evacuation plan for salmon farm workers stated that these should remain in safe zones around the coast of the fjord which, while being safe from the volcanic threat, were completely exposed to the tsunami which eventually hit.[15]

For their part, the general population were unable to accept the existence of multiple hypotheses, seeing this as an inability on the part of the scientists to find a precise solution. This demonstrated the general lack of understanding of scientific methods and resulted in disdain for the assembled experts and a lack of trust in the various decisions taken based on the proposed scenarios. In the eyes of local communities, the scientists' quasi-messianic position as experts became the object of derision and disregard [5].

4.3. Communication of risk and uncertainty as risk factors in themselves

The authorities assumed the role of filter and interpreter of scientific information and, in doing so, distorted the message. Fig. 4 presents the controversy according to the discourses of experts and political and administrative figures. Notwithstanding the profusion of contradictory

[13] See, for example: "SERNAGEOMIN y la Crisis Sísmica en Aisén: Estado Actual de un Proceso Complejo" (SERNAGEOMIN and the Seismic Crisis in Aysén: The Current State of a Complex Process), Press Statement 27 April 2007, SERNAGEOMIN.

[14] On 6 April 2009 an earthquake of Mw 6.3 flattened the Italian town of L'Aquila. According to official figures, 308 people died, 1500 were injured and 50,000 lost their homes. In 2012, following a trial lasting almost a year, seven scientists from the Italian National Commission for the Forecast and Prevention of Major Risks were sentenced to six years in prison for involuntary manslaughter. The judges ruled that their opinion as experts indirectly caused the deaths of at least 29 people, as the scientists' assessment and subsequent statement gave people a false sense of security when in reality they were in grave danger and should have been prepared. In 2014, the Court of Appeal quashed the convictions of six of the seven members of the Major Risks Commission. The other member, former vice-president of the Civil Protection Agency's technical department, was instead given a two-year suspended sentence.

[15] These plans went largely unheeded and the majority of salmon workers made their way to higher ground.

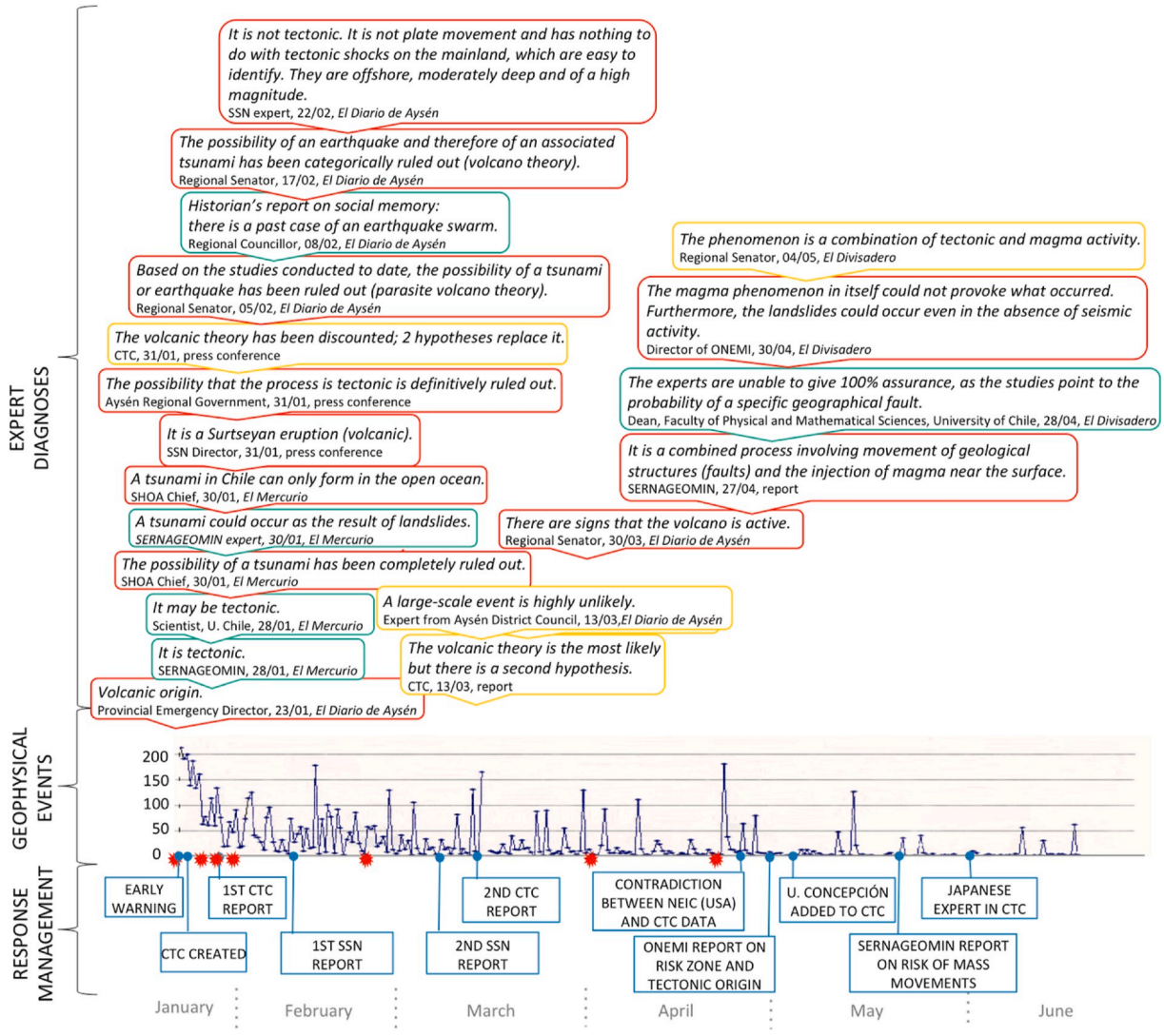

Fig. 4. The scientific controversy according to expert discourse Legend: Top (expert assessments): Quotations from experts in reports and press content. In red: incorrect diagnoses. In yellow: partially incorrect diagnoses. In green: correct diagnoses. *Middle (geophysical events): daily earthquake count.* ✸: *main earthquakes in terms of magnitude.* Bottom (management of the response): Principle actions on the part of experts during the response. CTC = Scientific Technical Committee (ONEMI). COE = Emergency Operations Committee (ONEMI). SSN = National Seismological Service. NEIC = National Earthquake Information Center (part of the United States Geological Survey).

diagnoses and discourses, it is worth mentioning the basic conceptual shortcuts taken in the communication of the risk, and how these resulted ultimately in an incomprehensible message [56,57].

Throughout the crisis, all of the scientific and technical reports and meetings maintained the possibility of two scenarios; however, in press communications, response management reports and information disseminated to the population, the tectonic hypothesis was repeatedly and categorically ruled out. This simplification of the scientific diagnosis was evident in both discourse and practice, affecting the response measures over the course of three months and leading to the release by ONEMI of a document that denied the possibility of a tsunami.

While this simplification was defended by political and administrative actors as a deliberate decision made to aid communication with the population, in reality it hindered efforts to alert inhabitants to the true range of risk scenarios present.

Subsequent reports on the crisis contribute further evidence of the lack of scientific understanding on the part of political and administrative figures, suggesting that simplification went beyond a mere intentional act, and in fact resulted from conceptual ignorance on the part of the authorities [2].

This denial of risk scenarios not only led to the dissemination of incorrect information to the population, but to the implementation of emergency measures that in fact increased the level of risk, as was the case with the designation of safe zones around the shores of the fjord, which in reality were liable to inundation. Thus, the contingency discourses and plans developed by the political, administrative and technical system failed to apply the principle of caution which, given the level of uncertainty with regard to diagnosis, would have resulted in the adoption of effective and proportional safety and risk mitigation measures.

Significantly, one of the main questions raised in the aftermath of the crisis was in relation to communication of the uncertainty of the scientific diagnosis. The complaints brought against the State (initially against ONEMI as the competent and specialised authority responsible for risk management, and subsequently against the then Interior Minister, Belisario Velasco) by family members of tsunami victims pointed the finger of blame at the State for "not warning local residents of the

danger" and broadcasting incorrect information that "ruled out all risk of an earthquake".[16] The judiciary rejected the claims, blaming failures on scientific disagreement and the lack of clear conceptual differentiation between terms such as *sismo* (a word that refers to all forms of earth movements, including minor tremors), *terremoto* (earthquake), and *enjambre sísmico* (earthquake swarm), returning the focus of the discussion to scientific uncertainty.

4.4. The experts

The issue of scientific construction of knowledge goes hand in hand with the question of expertise and its incorporation into the decision-making process. The characteristics of the *expert* have evolved over time, particularly in regard to their relationship to public administration and decision makers, and have today become part of a crisis of confidence and legitimacy. Originally, an expert was an individual recognised for their knowledge, experience and standing within their profession. They are also considered specialists based on their practical experience in a given area, as a result of which their input is requested by different areas to support decision making. More recently, the expert has been requested to conduct studies whose results help to solve complex, new and unusual situations [58].

Choice of experts to provide guidance to administrative actors is an unregulated process which is highly dependent upon the judgement, knowledge and contacts of those in charge. Whether to consult universities and research centres, which institutions will be invited, and who will coordinate their activities are all open questions that are answered on a case-by-case basis. The composition of the ONEMI Scientific Technical Committee caused disagreement in Aysén which grew in intensity alongside uncertainty surrounding the diagnosis, and this situation ultimately became politicised. Each actor involved was backed by their own expert, and the latter's evidence and diagnosis justified in each case the position taken by that actor.

With regard to the questioning of experts, our case study revealed an important point concerning relationships between qualified information, institutional networks, and decision making. From the very outset, the Scientific Technical Committee strongly favoured the hypothesis of volcanic origins and downplayed the probability of the tectonic theory and associated risk of tsunami in the fjord, despite the lack of a sufficient scientific basis to do so.

This inclination towards the volcanic cause stemmed from recent volcanic activity in the region which had brought together a number of institutions to manage the situation; it was these same institutions which once again came together in response to the earthquake crisis. Management of the emergency came under the remit of ONEMI. Historically, ONEMI and its employees have been closely associated with SERNAGEOMIN, and the latter became the main consultant to ONEMI during the Aysén 2007 event. SERNAGEOMIN's speciality lies in volcanic and geological hazards, and despite insufficient data to back up hypotheses B, C and D, the theory most closely aligned to SERNAGEOMIN's area of expertise was chosen. In other words, there was a *social construction* of the scientific assessment, and the announcement ("it's volcanic") led to practices and specific management measures – to the exclusion of others – as part of a *collective process*.

The expert committee was formed of scientists and technical figures from the geosciences and from Santiago-based institutions which compared the expression of the phenomenon (in terms of magnitudes and accelerations) with major seismic events that had occurred in the North-Central Zone, playing down the risk perceived by the population and claiming that it was due simply to a lack of familiarity on their part. This centralist approach to the phenomenon failed to take into consideration the specific nature of the region in which it was occurring, and even resorted to the study of events outside the region as a point of reference upon which to base possible hypotheses.

A conceptual error made repeatedly by experts was the denial of the possibility of a tsunami. This was rejected because the experts assumed that the concept of *tsunami* could only apply to ocean tsunamis caused by a subduction earthquake, something which occurs more frequently in the North-Central Zone. The term *marejada* (or 'storm surge', referring to a completely different, climatic phenomenon) was used repeatedly in reference to the possibility of a large wave in the fjord, or to a *fjord tsunami*. Thus, the particular reality of the Aysén region was ignored and the events that were unfolding were viewed in terms of the subduction earthquakes and tsunamis of the North-Central Zone.

4.5. Exclusion of informal sources of knowledge

The assessment of the Scientific Technical Committee and the decisions of the authorities ruled out the use of informal sources, initially in the form of testimonials from residents of Puerto Aysén recalling the occurrence of a similar series of earthquakes during the 1920s in close proximity to the fjord. These accounts were published early on by residents and the local authorities.[17] They were then confirmed by historical sources, including reports by geologist Max Yunge, an expeditionary contracted by the Chilean State during the initial phase of colonisation of the southern part of the country, in which he wrote of his encounter with large waves and landslides during his crossing of the Aysén fjord in his boat, El Inca, in 1927 [5]. Both the social memory of the inhabitants and historical records from the local area were presented and discussed during Scientific Technical Committee meetings, as well as during the two emergency committee meetings [2]. However, these sources were ignored due to their non-scientific nature and were overshadowed by a broad background of events, including the eruption of the submarine volcano that created Surtsey Island near Iceland.[18] This led to questions as to whether references to events abroad constitute valid, authoritative arguments in Chile.

The complete rejection of this informal knowledge by the experts contributed to the increase of tsunami risk. Perceptions and memories of local people were ignored. Comparison with events from very different geographical places was preferred in order to establish a diagnosis. All of this led to an incorrect assessment of the risk which, in itself, constituted a risk factor.

The 2007 Aysén crisis is a clear illustration of the problems surrounding governance of knowledge and information in Chile, and how these became a factor that increased levels of risk. We suggest that these problems are not coincidental and will now reflect on the limitations of expert knowledge construction.

4.6. Expert knowledge called into question

Scientific knowledge, or the lack thereof, was considered to be a fundamental factor in the crisis; this knowledge is not circumstantial but responds to the structural way in which science is conducted in Chile.

The first finding is the limited number of studies relating to disaster risk, which constituted no more than 0.5% of all FONDECYT research between 1997 and 2014, despite the acute relevance of the subject to the development of a country so exposed to multiple hazards and recognised vulnerabilities. FONDECYT projects concerning Patagonia were also limited in number; in the last two decades, funding has been given to only five academic studies relating to risk in Patagonia.

[16] "Rechazan demanda contra Belisario Velasco por tsunami en Aysén en 2007" (Claims against Belisario Velasco for 2007 Aysén tsunami rejected), 12 February 2013, Source: Emol.

[17] See, for example, the publication by Regional Councillor Eligio Montecinos, "Hay antecedentes de actividad sísmica en Aysén" (There is a history of seismic activity in Aysén), 8 February 2007 in the newspaper *El Diario de Aysén*.

[18] A statement made during a Scientific Technical Committee press conference, 31 January 2007.

Moreover, around 70% of those projects with a focus on disasters specific to the Patagonian regions were conducted in the country's three principal urban centres – Santiago, Concepción and Valparaíso – rather than being produced by regional researchers, reflecting the highly centralised character of Chilean scientific institutions. The geographical origins of scientific projects relating to Patagonia and/or disaster risk are presented in Fig. 5 (top).

The review also revealed the scant dissemination and social impact of projects focusing on risk and disaster, both at the national and local level, due to restricted access to study results. The accessibility of results from scientific projects relating to Patagonia and/or disaster risk are presented in Fig. 5 (bottom). More than half of the research reviewed does not even include access to a final report, although this is required by public scientific funds; between 15 and 24% of the projects have accessible final reports but don't grant access to the project's products (primarily articles published in scientific journals) either because they must be payed or because they were produced in a non-local language; 2% or less of the projects have both final reports and accessible scientific products; less than 29% of the projects have accessible final reports, scientific products and dissemination products. In the case of studies concerning Patagonia disaster risk, there is no accessible products from the scientific projects, raising the question of the local usefulness and usability of this scientific knowledge.

This issue of dissemination of the knowledge and results produced by scientific studies was addressed by CONICYT between 2011 and 2016, during which time one of the conditions of funding was the inclusion of science communication activities. Although this condition is generally upheld today, it tends no longer to be a requirement.

With studies concerning regional productivity (funded by CORFO or FONDEF) we see the same lack of attention paid to associated disaster risk. There are no FONDEF studies addressing natural hazards in Aysén. Between 1997 and 2015, only ten studies concerning the Aysén region received funding from FONDEF; with an annual average of around 200 studies funded, this is equivalent to 0.5% of all work. In 2008, a project financed by CORFO addressed the risk of disasters to salmon farming in the Aysén fjord and mentioned the recent swarm event. Fig. 6 shows the distribution of CORFO projects by productive area, illustrating the lack of priority given to the subject of risk in these studies.

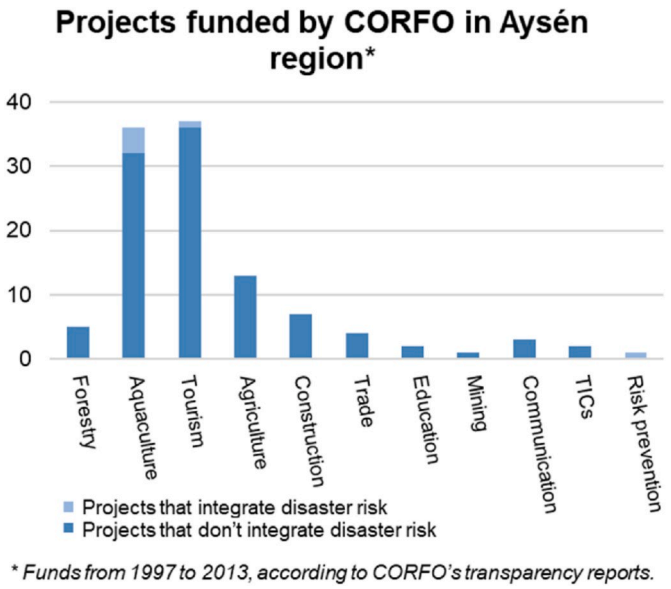

Fig. 6. Consideration of disaster risk in projects in the Aysén region funded by the Economic Development Agency (CORFO).

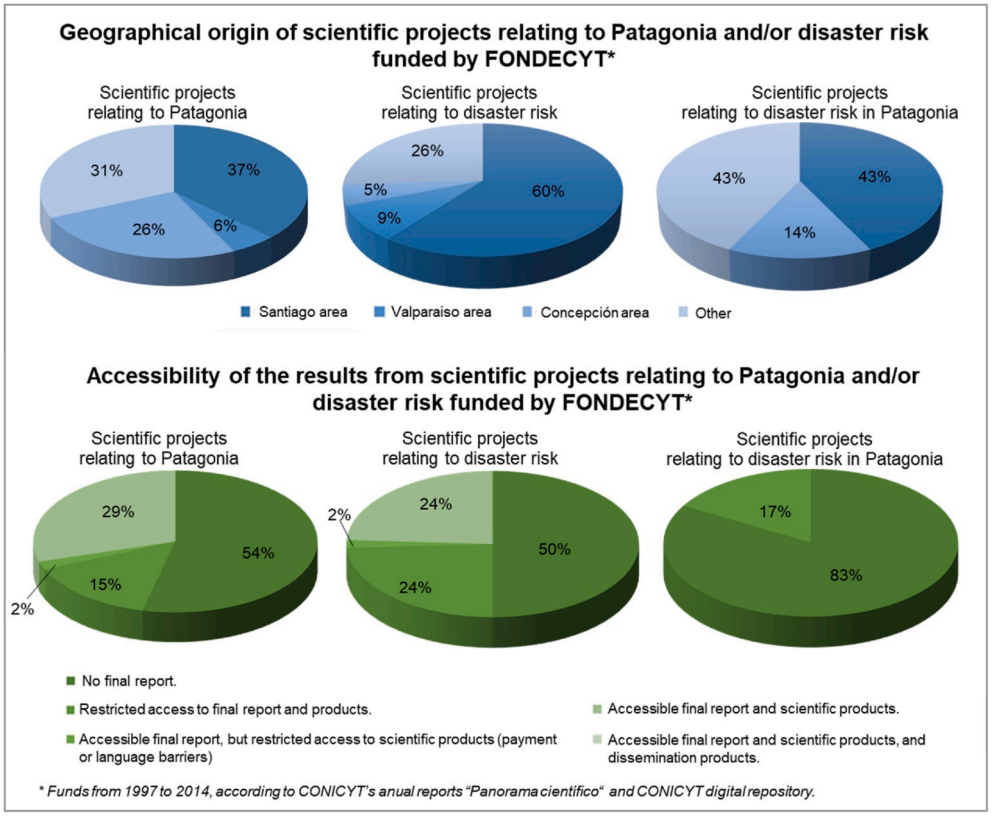

Fig. 5. Accessibility and origin of studies concerning disasters in the Aysén region.

5. Discussion

Jaime Miranda [59] studied the contribution of academic work to public policy, in particular that relating to environmental issues. Miranda shows that, despite high quality Chilean academic production (based on number of citations), scientific knowledge tends not to be taken into consideration by legislators.

The 2010 earthquake occurred in a seismic gap identified by scientists and monitored using GPS and accelerograph instruments since the 1990s. In the field of seismology, a number of studies had been published concerning deformations in the region. In particular, work by a Franco-Chilean team published only a few months before the earthquake hit concluded that the seismic gap between the cities of Constitución and Concepción presented the right conditions for a potential mega-earthquake of between Mw 8 and 8.5 [60]. The lack of preparation and anticipation surrounding the 2010 disaster once again cast doubt upon the impact of scientific knowledge on public policy.

Similarly, the primary instrument used for measurement of scientific productivity by institutions responsible for allocation of research funding is the number of articles published in academic journals indexed by the Web of Science. In the case of geoscientific fields, these are generally international English language journals with pay walls, a situation which hinders the transfer of knowledge to other social actors. This not only calls into question the impact of Chilean science in Chile, but also presents the possibility that Chilean science financed by limited State funding[19] may have greater impact in international scientific circles than within the country itself, implying a possible brain drain created by the same mechanisms that measure the success of scientific production.

During the Aysén event, the most effective media outlets in terms of coverage were the local radio stations (Radio Milenaria, Radio Aysén, Radio Las Nieves), but these "lack resources and the majority of their staff lack training" [5]. The local newspapers (El Divisadero, El Diario de Aysén) have neither large circulations nor the resources to go into great depth in their news stories. In fact, the clearest infographics and most detailed explanations of the various scientific diagnoses appeared in national newspapers (for example, El Mercurio, "Tres posibles sospechosos" (Three potential culprits), 30 January 2007), and not in the local press. Institutional websites and blogs were generally not consulted. For their part, those scientists consulted by the media complained of "ridiculous questions" posed by journalists [2].

The dysfunctionality of the press in its role as a communicator of information is not incidental, but illustrative of science and technology communication practices in Chile. According to Valderrama et al. [61]; despite steady growth in scientific productivity over the past decade, science and technology communication in Chile remains limited for a number of reasons:

1. Coverage of science and technology by the national press is poor, representing around 1% of all content. Chile has one of the lowest levels of coverage of these subjects on the continent.
2. The majority of science communication is led by institutions, primarily the country's universities. This explains the lack of communication of scientific issues in regions with limited or non-existent academic presence, as was the case of Aysén in 2007.
3. Chilean journalists lack specific training in science and technology.

In addition, in the context of post-normal science, in order to question scientific production, an understanding of scientific constructs is also needed, in this case those of geophysics and seismology. The latter is a relatively young discipline within the physical sciences, and advances have been made primarily during the 20th century. Concepts used commonly in the communication of complex geophysical events, such as *aftershocks* and, in the case of Aysén 2007, *earthquake swarm*, are a source of disagreement within the scientific community. Simplification of scientific discourse leads to categorical affirmations that are at times taken out of the context of the knowledge from which the discourse arises, thus distorting scientific information.

The characteristics of scientific practice revealed by the present analysis constitute structural elements that explain why, when the earthquake swarm hit in 2007, there was a lack of prior knowledge of the region, of monitoring of natural hazards, of scientific competence in the region, and of understanding of geophysical phenomena on the part of the authorities and the population.

6. Conclusions

This interdisciplinary review of the geophysical, technical and social crisis that occurred in Aysén in 2007 sought to explore the structural factors of the risk management and response systems present in Chile. We have provided evidence that the relationships between the different actors and the scientific and technical knowledge and information available constituted one of the factors that contributed to the crisis.

We have shown that the scientific diagnoses and the uncertainty associated with them led to greater perceived risk and the implementation of contingency plans that in fact worsened that risk.

The study also reveals the way in which the physical characterization of the phenomenon was socially constructed by experts, points to the subjectivity of the latter and to their favouring of a hypothesis according to institutional ties, an issue which calls into question the mechanisms by which scientists and holders of technical knowledge are brought on board in emergency situations in Chile.

The lack of certainty in the scientific diagnosis was due in part to a lack of knowledge about the territory, owing in turn to the lack of a scientific agenda that would include knowledge of the territory as an objective, including consideration of disaster risk across the various initiatives [62].

On top of this, science funding in Chile does not guarantee the harmonious development of those areas of knowledge necessary to the formulation of public policy applicable to each region. Furthermore, transfer of newly generated knowledge to those actors responsible for risk management and via the media to the general population is also seriously lacking. In summary, when the Aysén crisis of 2007 emerged, scientific knowledge and information were factors that increased the risk surrounding the disaster.

From the detailed analysis of the chain of events that led to Aysén crisis, of the scientific controversy role in risk production, and the root causes in institutional arrangements of risk knowledge actors, our case study demonstrates that it is not sufficient simply to produce expert knowledge within confined environments; it is not enough to focus on *how much* science is produced, but rather *what* knowledge needs to be produced and *how* to do so in order to guarantee its usefulness to society.

In view of the Chilean national context, in particular the creation of a new Public University in Aysén's region in 2015 to make up for the lack of academic activity in the region, the creation of a new Ministry of Science and Technology in Chile in 2018, and considering the international context with regard to the Sendai Action Framework and its call

[19] In 2015, the public budget for science, technology and innovation was equal to 0.37% of GDP (around 600 billion Chilean Pesos), significantly lower than the average science spending of OECD countries (2.4%) and of other countries in the region: Argentina spent 0.75% of its GDP, and Brazil over 1% (Source: UNESCO Institute for Statistics. Data obtained from https://datos.bancomundial.org/on 26 September 2017).

for development of science and technology in support of the reduction of disaster risk,[20] the present study contributes to reflection on the institutionality that needs to be created in order to advance in the generation of meaningful scientific production in accordance with communities and their needs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2020.101639.

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