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Short- and long-term evacuation of people and livestock during a volcanic crisis: lessons from the 1991 eruption of Volcán Hudson, Chile

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Abstract

Human and livestock evacuation during volcanic crises is an essential component of volcanic risk management. This study investigates the evacuation of human and livestock populations from areas impacted by ashfall from the 1991 Hudson eruption, Patagonia. The eruption was one of the largest in the 20th century resulting in significant impacts on rural communities in affected areas, including the evacuation of people and livestock. In the short-term (<3 months), evacuation of people from farms and rural towns was driven primarily by ashfall and ash storm impacts on public health and essential services. Severe impacts on livestock and the inability to restore vegetation growth following pasture burial, also meant pastoral farming became unsustainable in the short term. This resulted in evacuation of farms for usually <1, but up to 4 years following the ashfall and subsequent intense ash-storms. In areas of very heavy ashfall (>1 m) or where agricultural systems were stressed (from drought and long-term low commodity prices) many farms were abandoned, resulting in permanent migration of the farm population. Farms and farmers under pressure from marginal economic returns were the least likely to cope with the 'shock' of the ashfall. The financial capacity of farmers was important in their resilience and ability to return once conditions improved, although emotional attachment to the land sometime outweighed financial considerations. Evacuation of livestock in areas affected by ash falls was undertaken by many farmers, but it was not very successful or economically justifiable. Access for livestock trucks to the impacted area was difficult due to a poor road network, ashfall and snow induced blockage, and remobilised ash inhibiting visibility. The lack of reliable records of livestock populations inhibited evacuation and efforts to supply supplementary feed to the remaining livestock. The very poor condition of livestock prior to the eruption and burial of feed following the eruption often made evacuation uneconomic as well as reducing livestock resilience to cope with the eruption and transport impacts. The lack of capacity within the local livestock market and lack of available grazing land for the influx of transported livestock were also key failings of the evacuation effort.

Keywords: Volcanic ash, Volcán Hudson, evacuation, volcanic hazards, livestock, emergency management

1. Introduction

Volcanic eruptions produce a range of hazards that can endanger life and have wider societal impacts such as on agricultural activities, requiring mass evacuation of human and livestock populations. Mass evacuation from a particular area is necessary when volcanic hazards threaten the safety of those within the area (pre-impact) or following the impact of a hazard which has subsequently rendered the area uninhabitable (post-impact). Volcanic eruptions may also continue for years to decades causing on-going damage and risk to life which curtail recovery efforts and require the long-term evacuation of communities. Many human evacuations during volcanic crises have been recorded globally (see Table 1 for examples). Witham (2005) estimated over 5 million people were evacuated or affected by 248 volcanic events during the 20th century. Advances in volcanic risk management, particularly volcano surveillance (monitoring), which can provide timely evacuation

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Table 1 Selected human and livestock evacuations during volcanic crises

Eruption	Area Impacted	Details	Reference
1886 Tarawera eruption	Bay of Plenty, New Zealand	An estimated 20,000 livestock were evacuated from areas receiving >10 mm of ashfall.	Keam 1988
1973 Eldfell eruption	Heimaey, Iceland	Within 6 hours of the eruption nearly all of Heimaey's 5,300 residents had been evacuated to the Icelandic mainland. Several hundred sheep were evacuated to the mainland, whilst remaining cattle and poultry were slaughtered	Williams & Moore 1983; Wilson 2009
1976-77 Soufrière eruption	Guadeloupe, West Indies	Approximately 73,500 people were temporarily evacuated, mostly from Plymouth, the island's capital.	McGuire et al. 2009
1980 Mt St Helens eruption	Washington, United States	35 property owners at Spirit Lake evacuated and an exclusion zone established.	The Daily News/The Journal America 1980
1986 Nevado del Ruiz eruption	Tomila, Columbia	15,000 people evacuated in low-lying areas due to lahar hazards (*in the aftermath of the destruction of Armero town by lahars following a small eruption in 1985*).	Voight 1989
1990-1995 Unzen eruption	Shimabara, Japan	At the peak of the crisis, over 160,000 people used short-term evacuation accommodation, and nearly 5,669 used temporary housing for a period of up to four and half years due to pyroclastic flow hazards.	Shimizu et al. 2007
1991 Pinatubo eruption	Luzon, Philippines	Over 200,000 people were evacuated from around Pinatubo due to pyroclastic flow, heavy ash fall and lahar hazards. Significant subsequent lahar hazards resulted in on-going evacuations by returnees.	Newhall et al. 1997
1995-present Soufriere Hills eruption	Montserrat, West Indies	Approximately two thirds of the ~12,000 island's inhabitants were evacuated between 1995-97. On-going activity has led to their long-term displacement.	Clay et al. 1999; McGuire et al. 2009
1999 Tungurahua eruption	Tungurahua, Ecuador	Enforced evacuation of the entire population (16,000) from Baños due to potential pyroclastic flow, lahar and ashfall hazards.	Tobin & Whiteford 2002; Lane et al. 2003
2002 Nyiragongo eruption	Goma, Democratic Republic of Congo	Lava flows forced the evacuation of ~300,000 people from Goma city and surrounds and left 120,000 homeless.	UNDP 2004
2006 Merapi eruption	Yogyakarta, Indonesia	Over 20,000 people evacuated from western and southern flanks of Merapi due to pyroclastic flow and lahar hazards. Livestock remained on farms within the evacuation zone and tended to by farmers travelling in and out during the day. Many farmers attempted to sell livestock following feed destruction and isolation from their farms.	Wilson et al. 2007
2008-present Chaiten eruption	Northern Patagonia, Chile	Preventative evacuation of ~5,000 people occurred from proximal areas due to potential pyroclastic flow and lahar hazards, particular Chaiten town. Some evacuation occurred in rural areas from heavy ashfall hazards. Over 20,000 cattle were evacuated from areas impacted by heavy ashfalls in the weeks following the eruption.	Lara 2009

warnings have dramatically reduced casualties from volcanic hazards over the past 20 years (Witham 2005).

Mass evacuations during volcanic crises are commonly used to mitigate proximal volcanic hazards, such as pyroclastic flows, lahars, volcanic gases, landslides and lava flows (Table 1). However, volcanic ashfall may also impact human and animal health, water supplies, critical infrastructure, buildings, and agricultural activities which in turn drives evacuations (Cook et al. 1981; Blong 1984; Baxter 1986; Cronin et al. 1998; Neild et al. 1998; Johnston et al. 2000; Stewart et al. 2006; IVHHN 2007; Wilson & Cole 2007). Additionally, remobilisation of pyroclastic deposits by water and wind can cause regional scale impacts to exposed populations motivating prolonged evacuation and ultimately relocation of communities from an area. An obvious example was the evacuation and ultimately relocation of thousands of people in central Luzon, Philippines, due to on-going, widespread lahars following the 1991 Pinatubo eruption (Janda et al. 1996). The extreme impacts that a volcanic eruption may cause, may be the catalysts for social change depending on the pre-existing economic, social and political environments, accelerating the rate at which adjustments in social and political institutions occur (Blong 1984; Tobin & Whiteford 2002). However, beyond the Pinatubo eruption, there are few studies examining post-impact evacuations driven by acute primary ashfall and chronic secondary reworking of pyroclastic deposits; and how this has affected the long-term recovery of a region.

Similarly, there have been few accounts of livestock evacuation during volcanic crises. This is despite agriculture being a common land-use in volcanic areas (Table 1) and livestock having significant economic and emotional value to farmers (Annen & Wagner 2003; Jenner 2007; Wilson et al. 2009). There is scarce information examining whether the evacuation of livestock increases the motivation of farmers to evacuate (Wilson et al. 2009). Despite other studies suggesting that the willingness or reluctance to evacuate are determined by factors which include: an individual's perception whether evacuation will lead to a positive outcome; fears that property (e.g. livestock and agricultural produce) will be destroyed or stolen if left behind; and attachment to place (e.g. Blong 1984; Mileti et al. 1991; Lindell and Perry 1992; Cola 1996; Dibben & Chester 1999; Tobin & Whiteford 2002; LEGS 2009). With increased livestock trading and transport in modern agricultural systems, the mass evacuation of livestock is considered a popular option by farmers (Wilson et al. 2009). It is a controversial management response following recent volcanic crises, where it was rejected as a possibility by agricultural officials during the 1995/96 Ruapehu eruptions in New Zealand (Neild et al. 1998; Wilson et al. 2009), but was utilised within days of the 2008 eruption of Chaiten, Chile (T. M. Wilson, *unpublished field data*).

There is growing international recognition that during disaster response saving livelihoods through support to key livelihood assets, in addition to saving people's lives, can have a significant bearing on short- and long-term recovery outcomes for livestock dependent or reliant communities. A key example is the Livestock Emergency Guidelines and Standards (LEGS) project which aims to increase the quality of emergency response when livestock are key social and economic assets for the affected community by promoting international guidelines and minimum standards for the design, implementation and assessment of livestock interventions during disasters (LEGS 2009). Society has also increased its awareness of zoological vulnerability for livestock and is significantly less tolerant of widespread livestock losses in the aftermath of a disaster. Beyond the obvious economic loss, the significant psychosocial impacts to individuals when valued animals are lost or harmed, and the negative reputational impacts to region's and countries following mass fatalities of livestock has demanded increasing attention from emergency managers (Irvine 2009).

This study investigates the evacuation, relocation and return of human and livestock populations in areas impacted by ashfall from the 1991 Hudson eruption, Patagonia. It seeks to interpret the drivers causing farmers to evacuate and in some cases abandon farms, the agronomic and social impacts of the evacuation, the rationale and execution of livestock evacuation, and the factors that encouraged farmers to return to evacuated or abandoned farms. Field work was completed between 20 January and 8 February 2008 in the region of southern Patagonia impacted by the 12-15 August 1991 ashfall (Figure 1). Farming communities were visited in a transect from the upper Río Ibáñez valley in Chile, which received >1 m of ashfall, to the distal portions of the ash plume at the Atlantic coast of Santa Cruz province, Argentina (Figure 1). Field methods included semi-structured interviews with 32 farmers, and 11

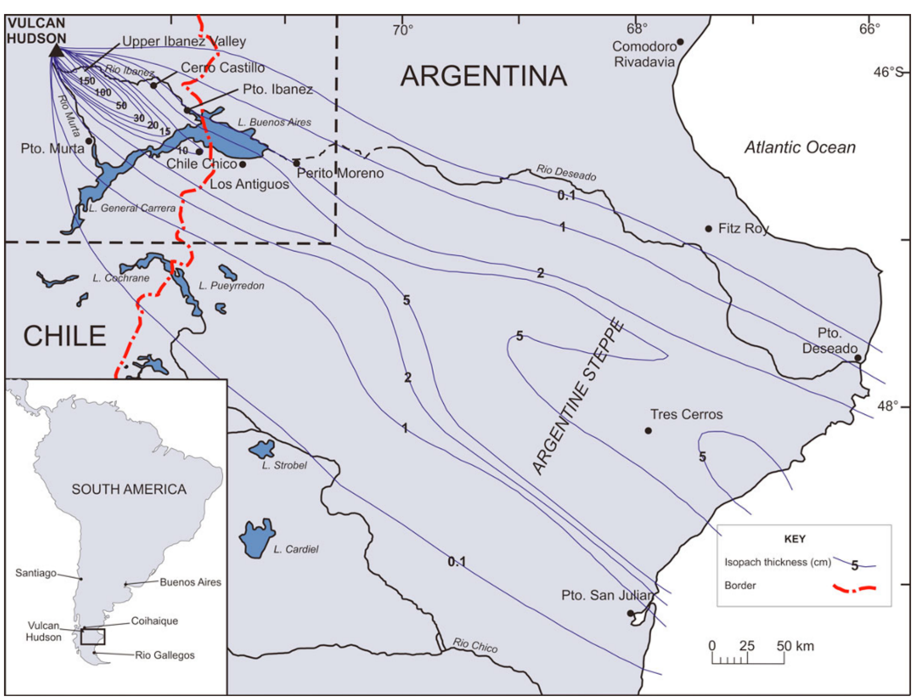

Figure 1 Location map and isopach map of eruptive deposits of the 12-15 August 1991 Hudson eruption (after Scasso et al. 1994**).** Figure 2 is shown as a dashed box.

municipal officials or agricultural experts (e.g., veterinarians or agricultural field officers) who had experienced the 12-15 August 1991 eruption or participated in the response and recovery operations.

2. The 1991 eruption of Volcán Hudson

Volcán Hudson (45°54’ S; 72°58’ W) is part of the Chilean Southern Volcanic Zone (33-46°S) (Kratzman et al. 2008). At least 12 Holocene explosive eruptions have occurred at Hudson, the most significant of which were eruptions 6,700 years before present (yrs BP), 3,600 yrs BP, and in 1991 (Naranjo & Stern 1998). The 1991 eruption consisted of two separate, partially sub-glacial phreatoplinian explosive phases on 8-9 August and 12-15 August 1991. It was the second phase of the eruption, on 12-15 August, 1991, that dispersed ash on a narrow, elongated ESE sector of Patagonia, covering a land area of more than 100 000 km^2 (Figure 1) and caused most of the evacuations.

The eruption produced 4.3 km^3 bulk volume (2.7 km^3 dense rock equivalent) of tephra fall deposits, making it one of the largest explosive eruptions of the 20th century (Kratzmann et al. 2008). The elongated shape of the deposit was the result of strong northwest winds.

3. Where did evacuation occur?

The area impacted by ashfall was climatically and ecologically diverse, resulting in a wide range of agricultural practices. The Ibáñez valley, in the southern Andean mountain range, west of Puerto Ibáñez supported low to medium intensity pastoral farming of sheep and some cattle (>700 mm of annual rainfall). The area surrounding Lago Gen. Carerra/Buenos Aires (Figure 2) has irrigated valleys supporting intensive pastoral and horticultural farming at Puerto Ibáñez, Chile Chico, Los Antiguos and Perito Moreno (200-500 mm annual rainfall). The vast arid steppe region that extends east to the Atlantic coast (Figure 1) supports low intensity extensive pastoral farming of sheep (<200 mm of annual rainfall) (Peri & Bloomberg 2002). The ashfall buried short winter pastures, forcing pastoral farmers to use what limited supplementary feed was available. Heavy snowfall also coincided with the ash deposition in the Andean regions. Farms were already overstocked, due to poor commodity prices for meat and wool in the previous season, adding further stress. Hence, in general, livestock were already in poor condition. Following ashfall, many suffered from starvation, and other health problems due to ingestion of ash with feed as well as being directly impacted by ashfall, which resulted in widespread livestock deaths (Rubin et al. 1994; Wilson 2009). Valdivia (1993) estimated >1 million sheep and several thousand cattle died in Chile and Argentina following the ashfall. High winds common to the area remobilised ash deposits, creating billowing clouds of fine ash (referred to as ash storms), which abraded and repeatedly covered pasture re-growth, exacerbating the impact (Wilson et al. 2011).

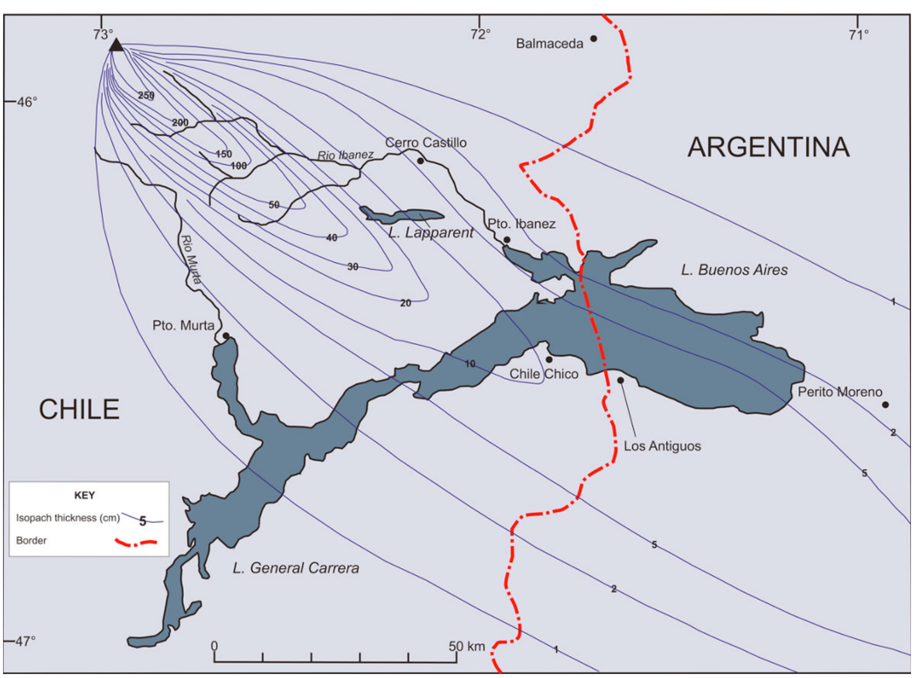

Figure 2 Location map and isopach map of the Ibanez River catchment (after Scasso et al. 1994).

Horticultural farms (in the irrigated valleys) were not initially affected, as crops and fruit trees were in winter dormancy or had yet to be planted. However subsequent ash storms during the crucial spring growth period (September to November) caused significant damage and loss of yields. People on farms and the small rural service towns in the impacted area had significant health problems due to the airborne ash during ashfalls and particularly during subsequent ash storms.

Farmers initially evacuated to the closest towns, such as Puerto Ibáñez, Chile Chico, Los Antiguos, Perito Moreno, Puerto San Julian and Tres Cerros, but eventually moved further away in search of employment. Many headed to regional centres such as Coihaique and Commodoro Rivadavia (Figure 1). Farmer evacuation from the three main agricultural areas impacted by ashfall is investigated below.

3.1 Ibáñez Valley

The initial focus of emergency managers responding to rural communities exposed to heavy ashfall was human safety. The Ibáñez valley received very heavy ashfalls (500->2000 mm; Figure 1; Naranjo et al. 1993) and most farmers evacuated, with many self-evacuating and others using army and ONEMI (Chilean Civil Defence) vehicles. The farming families generally left within hours or days of the eruption onset. Farms were small (100-200 ha) and carried low numbers of livestock, typically cattle with stocking rates of ~0.3/ha. The factors that led to interviewed farmers deciding to evacuate included: homestead roof collapse, or fear it may collapse (Table 2); concerns about health impacts from the ash, including homestead contamination and severe ongoing problems with wind-blown fine ash; fears of further ashfalls; lack of livestock feed following pasture burial and exhaustion of supplementary feed. Farmers described heavy ashfall and snow accumulations on homestead roofs requiring frequent cleaning to prevent collapse, particularly in areas that received >600 mm of ash (Table 2), which agrees with previous known instances of roof collapse from ashfall (Spence et al. 2005). Several farmers reported large lapilli breaking glass windows. In one case this occurred ~50 kilometres from the volcano. Homesteads were rapidly contaminated with ash. The limited available feed was also rapidly covered in thick (>200 mm) ash. Veterinarian Don Julio Cerda Cordero of Servicio Agrícola y Ganadero (SAG; a branch of the Chilean Ministry of Agriculture) reported that in extreme cases, ash ingestion with feed caused gastrointestinal blockages. Starvation and gastro-intestinal complications from ash consumption were also reported as the primary cause of livestock mortality (Rubin et al. 1994). There were few reports of contaminated water or water shortages as a significant problem for either people or animals, mostly because surface water supplies were spring fed and cleared quickly.

Most farmers interviewed had evacuated from the Ibáñez valley by 15 August. The remaining evacuees left by 30 August. Some farmers remained in government welfare centres and emergency accommodation in towns such as Cerro Castillo for up to 4 years, or relocated out of the area in search of work. Most farmers returned regularly to assess the vegetation recovery. Many farmers said they were very reluctant to leave their farms, citing strong financial and emotional attachment to their land and livestock.

3.2 Irrigated Valleys

High intensity mixed horticultural and pastoral farms (stocking rate >3/ha) and horticultural farms (typically fruit orchards) were located in river valleys with developed irrigation networks. They typically experienced between 50-120 mm of ashfall at Puerto Ibáñez, Chile Chico, Los Antiguos and Perito Moreno. These farms used cultivation and fertiliser improvement, permanent willow and poplar tree wind breaks, and were located close to population centres. Whilst not catastrophically impacted by ashfall, many mixed and horticultural farms were evacuated for weeks to several years, in response to health hazards (especially from wind remobilised ash) and uncertainty around future eruption impacts (Wilson 2009). One interviewee had evacuated from Los Antiguos due to the health hazards from airborne ash inflaming a chronic asthma condition. The family had

Table 2 Roof collapse mitigation actions

Ash & snow fall depth (farmer estimate)	Ashfall depth (Naranjo et al. 1993)	Distance from vent	Details
150 cm	90 cm	36 km	Roof collapsed on wooden constructed homestead, despite initial cleaning attempts
100-120 cm	35 cm	42 km	Regular cleaning required to prevent collapse on wooden construction homestead
80-100 cm	40 cm	73 km	Wooden constructed homestead & farm building roofs collapsed under weight of ash and snow - not cleared due to evacuation
50-60 cm	15 cm	54 km	No structural damage to wooden homestead. Regular roof cleaning due to fears of collapse.

evacuated for several months, during which most of their 70 sheep died due to starvation after ash buried pasture. Some farmers wished to evacuate due to health hazards, but remained on their farms because of fears of their houses being looted, the need to care for their livestock, and had missed any aid subsequently offered. Short-term evacuations of towns occurred during ash storms 1-6 months following the ashfall. Over 600 women and children evacuated from Chile Chico, Los Antiguos and Perito Moreno (Wilson et al. 2011).

Residents in Puerto Ibáñez, Chile Chico and Los Antiguos all reported cleaning ash from their roofs, fearful that they may collapse. Over 100 adobe-style buildings in Chile Chico suffered structural damage from the weight of ash on their roofs. Some totally collapsed, whilst many others had large cracks in load-bearing walls. Light snow and rainfall greatly increased the weight of the ash exacerbating the impacts. Most interviewees said they used shovels to remove ash from their roofs, because it was like cement and very heavy when it became wet.

Puerto Ibáñez municipal officials reported that there has been a significant population decline in the town and surrounding area, down from 4,000 in 1991 to 2,700 in 2001; a level at which it has since stabilised. In contrast to the upper Ibáñez valley area, widespread farm abandonment did not occur at Puerto Ibáñez with ash depths of 50-80 mm being initially more manageable. However, on-going ash-storms repeatedly damaged pastures, crops and livestock, and reduced soil fertility, causing agricultural recovery to be extremely slow and challenging (Wilson et al. 2011).

3.3 Steppe

Farms in the Argentine steppe are typically very large (often tens of thousands of hectares), run mostly sheep, and at very low stocking rates (<0.1/ha). This region experienced up to 80 mm of ashfall, but more typically fall deposits were between 1-50 mm (Scasso et al. 1994). This was enough to cover sparse feed resources and fill shallow watering holes. Extreme effects from wind remobilised ash exacerbated and prolonged these problems (Wilson et al. 2011). The fine ash (<0.5 mm) from primary ashfall and from ash storms penetrated houses, making them "uninhabitable". Farmers in the region evacuated into towns, such as Chile Chico, Los Antiguos, Perito Moreno and Puerto San Julian due to household contamination and health fears. Impacts on livestock were extreme, with starvation, acute dehydration, and tooth abrasion leading to widespread and severe livestock losses (Wilson et al. 2011; Rubin et al. 1994). Livestock watering holes were contaminated with primary and windblown ash, creating muddy "death traps" for starved and exhausted livestock. Livestock were dispersed across the large farms, making them difficult to muster for supplementary feeding and provision of fresh water. Ash-storms reduced visibility and made movement difficult, compounding recovery problems. The large steppe farms had few technological improvements, such as irrigation or wind breaks to mitigate impacts or assist recovery (Wilson 2009). The poor financial state of farmers limited any capacity to absorb losses and forced abandonment of many farms in the ensuing months, particularly as ash-storms continued to bury or destroy scarce feed.

A substantial human evacuation out of remote, extensive farming areas around Chile Chico, Los Antiguos, Tres Cerros and Puerto San Julian was reported following the ashfall and subsequent ash-storms (because of farm abandonments there were few farmers available to interview In the Argentine coastal steppe - therefore information was obtained by interviewing municipal officials and the former Mayor of Puerto San Julian). Farmers evacuated "temporarily" due to remobilised ash from strong winds and fine ash contaminating house interiors. However, this ultimately became permanent abandonment, because ash storms continued to damage vegetation and livestock. Farmers were forced to lay-off workers and ultimately abandon their farms. As many as 80% of extensive pastoral farmers in the steppe are thought to have abandoned their farms due to productivity losses and health effects from wind-blown ash, according to former Perito Moreno agricultural officer Shaquib Hamer. Farmer and mechanic Don Hugo Ciselli estimated 70-80% of people had left the Tres Cerros area (~100 people). He said approximately 50 farms have been abandoned in the area, but not sold, although recently (2008) 2-3 farmers have returned. Former Mayor of Puerto San Julian, Alberto James Alder reported that approximately 7,000 people were forced from their farms in the local area. Farmers evacuated immediately after and headed for town or relatives. Most went back periodically to check on their farms but ultimately realised sheep farming was no longer viable. These farms had been struggling prior to the eruption with dry conditions and low wool and meat commodity prices. The eruption and on-going ash-storms appeared to have accelerated their decline.

4. Livestock evacuation

A significant animal welfare crisis rapidly developed during and following the ashfall, with farms overstocked and the scarce feed buried under ash and snow. Farmers rapidly exhausted limited supplementary feed stocks, whilst Chilean government agricultural agencies SAG and the Instituto de Desarrollo Agropecuario (INDAP) attempted to organise and assist with evacuating livestock and sourcing further supplementary feed.

Livestock evacuation operations began in the Ibáñez valley area almost immediately and later in Chile Chico. Livestock trucks were used to bring in supplementary feed into the affected area including over 100,000 kg of molasses and 30,000 bales (30 × 40 × 120 cm) of hay. An estimated 5,000 cows and 3,000 sheep were evacuated out from all affected areas (Mario Christian Moreno, Regional Secretary, INDAP, pers. comm. 2008).

Interviewed SAG and INDAP officers recalled that there was significant confusion during the initial stages of the agricultural emergency response, particularly with respect to what should be done and how severe the impact was. Lack of an accurate livestock census was a significant deficiency for emergency response planning. The number of livestock thought to be in the area was significantly higher than official figures, which led to a major underestimation of the number of livestock requiring feeding and evacuation. Sourcing additional supplementary feed from surrounding regions was extremely difficult, due to the time of year and recent dry conditions. Logistical coordination problems impeded supplementary feed reaching staging posts in the disaster zone. Transporting the feed to impacted areas was also difficult, as ashfall covered roads and mixed with snow, making traction very difficult. Wind-blown ash inhibited visibility. Trucks were only operated on roads with thin to moderate ash falls (<50 mm of compacted ash), but the main access road into the Ibáñez valley became covered in heavy ash deposits making traction difficult. Rain and snow in mid-August turned the ash to thick mud, making access impossible for heavy vehicles, and required livestock to be walked out to staging points (Don Julio Cerda Cordero, *pers. comm*. 2008). Falling and remobilised ash dramatically cut visibility, making it difficult to drive. Evacuation/feeding operations had to be halted for several days from 15 August due to the poor conditions. Sheep and cows abandoned on farms chased vehicles, hoping they would be fed, and sometimes blocked road traffic. Ash deposits had compacted sufficiently by mid-September so that trucks could access farther up the Ibáñez valley (Don Julio Cerda Cordero *pers. comm*. 2008). However, the main evacuation efforts only lasted until early September (Mario Christian Moreno, Regional Secretary, INDAP, pers. comm. 2008). The Chilean government assisted by paying for supplementary feed, but did not assist with transportation costs (Don Julio Cerda Cordero, *pers. comm*. 2008).

The decision to evacuate livestock was in the hands of individual farmers and dependent on their financial means. Most were unable to evacuate. Some farmers even halted and unloaded their livestock from trucks, after government agricultural agencies had loaded their livestock onto trucks. There was no threshold of ash depth that dictated the necessity for evacuation. In some cases, light ashfalls contaminated water supplies forcing evacuation. In other cases there may have been significant thicknesses of ashfall, but with access to sufficient clean water and supplementary feed, animals could survive (Don Julio Cerda Cordero *pers. comm*. 2008). Cows were generally evacuated preferentially due to their higher value. Farmers were required to find a location where the livestock could go, so only those with contacts outside the impact zone were able to evacuate their livestock. When combined with the poor access to impacted areas and high animal mortality rates, only a low percentage of livestock in the heavily impacted areas were moved. Farmers who did evacuate their livestock were often later forced to sell them at very low prices to avoid paying for hired grazing. Often this did not cover the evacuation transport costs.

Uncertainty of health impacts on livestock, livestock feed availability, medium term pasture recovery and the threat of future eruptions motivated livestock (particularly cattle) evacuation from Chile Chico by ferry to Puerto Ibáñez and later by truck across the border at Los Antiguos, driving around Lago Buenos Aires and back into Chile. Argentine border controls were relaxed to assist the evacuation of people and livestock. Blocked roads meant livestock could not initially be evacuated from Los Antiguos, leading to severe losses in sheep herds from starvation once supplementary feed was exhausted. When roads reopened livestock feed was brought in and some animals transported for sale.

The speed of evacuation was crucial for animal welfare. Livestock were already in poor condition, and began dying within days of feed being covered by ash. Some evacuated livestock died during or immediately following evacuation due to gastro-intestinal complications, usually starvation related.

5. Impact of Farm Abandonment

Most farmers initially believed they would only evacuate their farms for a short-period (days to weeks). In the weeks, months and years after the eruption it became evident that wind-blown ash and household contamination (leading to health concerns) were continuing hazards. In many areas pastoral farming was no longer viable until vegetation recovered. Large scale livestock deaths and evacuations led to significant de-stocking of farms and otherwise compromising productivity. Land values were significantly depreciated, livestock assets all but lost, and with continuing impacts from ash storms, farmers were commonly forced from their lands, particularly in the Ibáñez valley and in the steppe region. Farmers leaving the area attempted to sell their farms, but struggled to find buyers or refused to accept the very low prices offered, so abandoned their farms but planned to return later. The Chilean government purchased some badly impacted farms in the worst affected areas of the Ibáñez valley, but there was no such support for farmers in the Argentinean steppe (Wilson 2009). This created a significant social problem, because the impacts drastically reduced farmer's financial equity and since most only knew sheep farming, they had few other employment prospects. All interviewed farmers said they had always expected to return to their farms, citing strong family ties and emotional attachment. In general, elderly farmers were more likely to evacuate their farms and were less likely to return, citing they did not have the physical or emotional energy to recover from the eruption event. The impact of the loss of financial equity was exacerbated and mentally crushing for displaced elderly farmers, who either expected to retire on their land or use the money from the sale of their farm to support retirement.

The death of animal populations on a large scale was also very difficult for pastoral farmers to cope with (Hall et al. 2004; Jenner 2007). Social and economic distribution from evacuation and reaching the difficult decision of whether to abandon farms compounded stress, and supports initiatives such as LEGS (2009).

5.1 Why did they return?

Many abandoned farms had been re-occupied in the Ibáñez valley by 2008. However, few had been returned to in the steppe region, despite having experienced thinner ashfalls. A key factor for returning was the sufficient recovery of vegetation. In the Ibáñez valley with increasing ash thickness, the duration of abandonment increased (Figure 3). Within 1-5 years many farms close to Cerro Castillo were inhabited again (50-70 mm ashfall). By 1994-95 reworking of ash by wind and water had in places slowed and had also exposed the original soil surface (Wilson 2009). In the upper Ibáñez valley with a total coverage of >500 mm ash, farms were abandoned for up to 10 years. Eventual vegetation recovery was aided by wind removing ash overburdens, and of spreading of seed and hay on the ash deposit to re-establish pastures. Despite re-habitation by 2008, agricultural production was extremely low compared to pre-eruption conditions. Areas with greater than 1.5 m ashfall did not support any farming in 2008. The poor chemical and physical fertility characteristics of the ash inhibit pasture re-establishment. Stabilisation of ash deposits against wind erosion was an important factor to allow vegetation recovery, especially in the dry, windy steppe region (Wilson 2009).

Factors influencing farmers' return included financial capacity, a decrease in health fears with the reduction of ash storms, and the strength of emotional attachment to the land. Farmers found it a challenge to raise the necessary funds to bring farms back into production, despite credit assistance available from government agricultural agencies, such as INDAP in Chile. In the steppe region, the huge cost of re-stocking and re-developing farms was a significant barrier. The three farmers interviewed who maintained farms either at Tres Cerros or Puerto San Julian maintained significant other business interests to provide financial security. Some farms diversified and changed land use practices. In the upper Ibáñez valley with ash >1 m, farmers mostly relied on lumber and fire wood extraction and carried few livestock. Farms were planted in exotic pine forestry in some areas with 1200 mm of ash. There was no evidence of land disputes between farmers or resettlement unrest occurring at Hudson, contrasting with the aftermath of the Parícutin eruption, where murders and suicides occurred (Rees 1979).

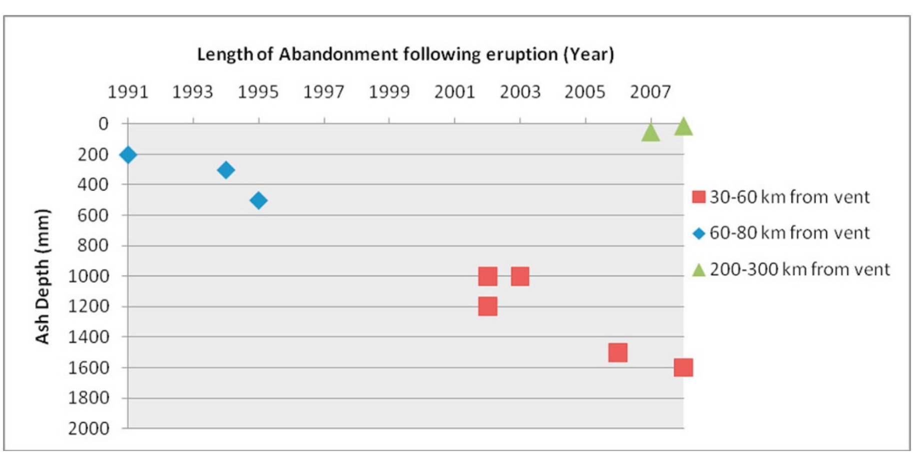

Figure 3 Time till farm reoccupation following the 1991 Hudson eruption (after Wilson 2009**).**

6. Limitations of the study

This is one of the first studies to study the fate of human and livestock populations following long term evacuation due to a large explosive volcanic eruption. It has acknowledged limitations; for example much of the information contained within this paper is of a qualitative nature, derived from semi-structured interviews. This approach allowed detailed and in-depth data collection on complex issues. But there are several limitations of this approach which must be acknowledged, including repeatability, potential for interviewer bias, relevance of qualitative data collected, difficulties in generalising one-on-one interviews, and validity (e.g. if the respondent is biased). In addition, there are few interviews with people who have permanently moved away from the impacted area. It is therefore not possible from this study to analyse the motivation to leave or the relative success, whether it be economic, social, psychological or otherwise, of those who have returned and those who have permanently left the region. Such data would be invaluable for shaping future disaster management planning.

This study highlights the importance of environmental (e.g. drought and windy conditions) and human systems context (e.g. low commodity prices) preceding and following the disaster event. However, one of the greatest limitations of this study is the lack of longitudinal demographic and socioeconomic data to more robustly analyse spatial and temporal changes to population and economic productivity following the 1991 ashfall. Wider sociological aspects, such as incidence of domestic violence and mental health problems over time, would also be of interest. Whilst we did not record any accounts of evacuated people causing antagonism when they moved to new communities outside the impact zone, as might have been anticipated (due to competition for resources for example; Lindell and Perry 1992; Hewitt 1997). Few interviews were in areas which had received evacuated people and sufficient time may have passed for this to have been forgotten.

7. Conclusions

The impacts from the ashfall and ash storms resulted in evacuations out of the area in the short and long term. The following types of responses were identified from interviews:

- Short-term (<3 months) evacuation of farms and rural towns due to ashfall and ash storm impacts on public health and essential services;
- Evacuation of farms for usually <1, but up to 4, years following ashfall and subsequent intense ash-storms, which reduced farm productivity in the short term by burying feed;
- Abandonment of farms and permanent migration (usually following farm sale) from areas that suffered a long-term decline of agricultural income due to destroyed vegetation and soil from ashfall and ash-storm effects, drought and falling commodity prices (usually in the steppe);

Widespread farm abandonments (>3 years) occurred in two areas with different climates, agricultural practices and which received very different ashfall depths; the Ibáñez valley (500->2000 mm), and the steppe region of extensive pastoral ranch style farming (<75 mm). Household contamination and health concerns from ashfall and ash storms motivated human evacuations from farms and rural towns up to hundreds of kilometres from the erupting volcano. Destruction of farm resources, such as pastures, soils and animals and inability to restore feed production, meant pastoral farming became unsustainable. This often turned the evacuation into abandonment, with farming only viable once vegetation recovered. The financial capacity of farmers was important in their resilience and in enabling their return once conditions improved (LEGS 2009). Farms and farmers under pressure from marginal economic returns were less likely to cope with the 'shock' of the ashfall. On-going impacts from ash storms and the financial requirements necessary to restock farms and invest in soils and pastures created further barriers to return to farming. Some farmers maintained other financial interests during this transition.

It is important to recognise the substantial loss of equity farmers suffered in their land and livestock value within days of heavy ashfall. This created major social problems and led to significant migration from the region. The most vulnerable were elderly farmers relying on the equity to assist retirement. Farmers who returned cited strong family ties, emotional attachment to the area, and residual economic value in the land as factors driving their decision, despite the hardships and low economic returns.

It has been recognised that people may not evacuate if there is no clear planning for their pets or livestock (Zeigler et al. 1981; Heath et al. 2001a;b; Hall et al. 2004; Hunt et al. 2008; LEGS 2009). Concerns for livestock dictated some farmer's actions when considering evacuation, but ultimately the death of animals, fear of roof collapse, and health concerns motivated most to evacuate. The evacuation of livestock was a secondary priority to human evacuation, but since livestock represent significant economic value to impacted farmers, there may be strong desire and even economic justification to remove livestock from an impact area. High livestock populations of large animals such as cattle create significant logistical problems, especially if road access is limited (Wilson et al. 2009). Evacuation of livestock around Hudson was not very successful nor economically justifiable. Livestock truck access to the impacted area was difficult due to limited roads, ashfall and snow induced blockage, and remobilised ash inhibiting visibility. The lack of reliable records of Chilean livestock populations severely inhibited evacuation and efforts to supply supplementary feed. The poor condition of livestock often made evacuation uneconomic as well as reducing the resilience of livestock to cope with the eruption impacts and the stresses of transport. The lack of capacity within the local livestock market and lack of available grazing for the influx of transported livestock were important failings of the evacuation effort.

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Authors' contributions
Please use the following format as an example, including using initials to refer to each author's contribution: TW carried out the research design, undertook the fieldwork and draft the manuscript. JC assisted in research design, carried out fieldwork and assisted in drafting the manuscript. DJ conceived of the study and participated in its design and coordination. SC assisted in the research design and significant revision of the manuscript. CS assisted in research design and carried out fieldwork. AD assisted in draft the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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