Nat Hazards (2015) 77:1619–1653
DOI 10.1007/s11069-015-1667-0

ORIGINAL PAPER

# Framing the 2010 Eyjafjallajökull volcanic eruption from a farming-disaster perspective

**Sólveig Thorvaldsdóttir · Ragnar Sigbjörnsson**

Received: 11 December 2013 / Accepted: 17 February 2015 / Published online: 28 February 2015


**Abstract** The aim of this paper was to shed light on the 2010 Eyjafjallajökull volcanic eruption in Iceland from a farming perspective to identify lessons for livelihood professions regarding disasters. Scientists had detected activity under the volcano for over a decade prior to the eruption and had notified the Civil Protection. Preparedness activities included disaster planning and training in evacuation procedures in the event of flooding caused by an eruption under the Eyjafjallajökull icecap. However, the main concern for farmers turned out to be ashfall. Previous research has shown that specialized information to farmers on ashfall was inadequate. Here, information is presented from a livelihood-disaster perspective and used as a basis for an analysis of pre-eruption, real-time and post-eruption activities by farming actors. The livelihood-disaster perspective is built on the Sustainable Livelihoods Framework and a set of eight disaster-related objectives. The study shows that farming actors were not informed about the scientific monitoring, not included in pre-eruption coordination by the Civil Protection but were indeed the main actors responding to the needs of farmers having ash problems in the weeks and months following the eruption. A literature survey shows that sufficient hazard, exposure and vulnerability information had been available prior to the eruption to produce useful risk-related information to inform risk reduction and contingency planning amongst farming actors. Livelihood professionals are highly specialized and should take the initiative in performing their own pre-disaster activities to effectively and efficiently assist their communities during a disaster.

**Keywords** Farming · Eyjafjallajökull volcano eruption · Livelihood-disaster perspective · Sustainable Livelihood Framework · Disaster-related objectives

S. Thorvaldsdóttir (✉)
Earthquake Engineering Research Centre, University of Iceland, Austurvegur 2A, 800 Selfoss, Iceland
e-mail: solveig@rainrace.com

R. Sigbjörnsson
Faculty of Engineering Science and Technology, Norwegian University of Science and Technology (NTNU), Rich. Birkelandsvei 1A, 7491 Trondheim, Norway

## 1 Introduction

By law, disaster coordination in Iceland is under the umbrella concept of Civil Protection. It is the responsibility of the police (Act on Civil Protection, *Lög um almannavarnir* 2008), at both the local (local chiefs of police) and national levels (National Commissioner of the Icelandic Police). In 2002, prompted by information from the scientific community, the local chief of police requested funding from the Ministry of Justice for a risk analysis and organized preparedness activities for a possible eruption of the Eyjafjallajökull volcano and flooding due to melting of the icecap (Thorkelsson 2013). In 2010, the police chief coordinated various response activities (Thorkelsson 2013). Previous research on the response to the 2010 Eyjafjallajökull volcano (EFJV) eruption shows that whilst emergency management agencies in Iceland responded immediately to ensure people's safety and disseminated geophysical information during the crisis, specific information with respect to ongoing problems associated with the ash was lacking, including specialized information for farmers (Bird and Gisladottir 2012).

Delivering the right information to the right people, in the right format, in the right place and at the right time is a key disaster-related activity (Iannella and Henricksen 2007), requiring good organization, concerted efforts and allocation of resources, along with knowledge of hazard phenomena (Alexander 2006). This study looks for explanations on why information to the farmers was inadequate, and what could have been done differently, in order to learn lessons for livelihood professions in general. The conceptual framework used here is a livelihood-disaster perspective. As implied, the perspective is a combination of a livelihood perspective and a disaster perspective. The Sustainable Livelihoods Framework (SLF) (DFID 1999) is used to define the farming perspective and guided the data collection. The eight disaster-related objectives of Disaster-Function Management (Thorvaldsdóttir and Sigbjörnsson 2014) define the disaster perspective and guide the analysis. The combined perspective is presented in a Venn diagram. Information and data are collected for each component in the Venn diagram from data sources on farming and the EFJV. The data sources include scientific literature and secondary information available prior to the eruption, field reports and interviews. Information from a

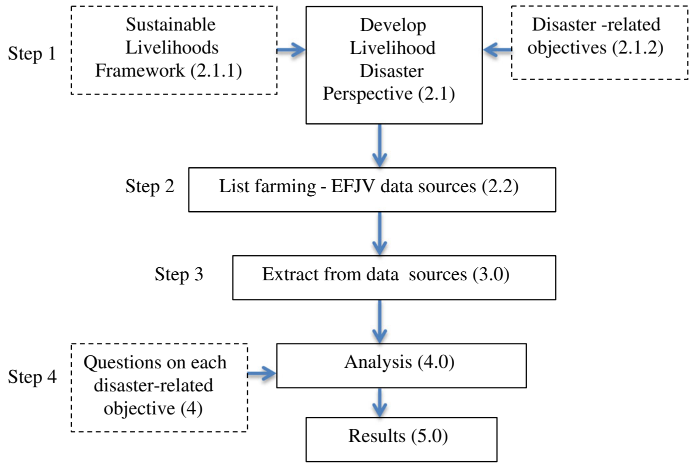



**Fig. 1** The method (numbers relate to sections)

reconnaissance mission performed by farming actors four weeks after the onset of the EFJV eruption provides insight into the problems and response within the farming community. Eleven actors identified in the report are interviewed for information about their pre-eruption, real-time and post-eruption activities. After the interviews, seven actors were defined as direct farming actors and included in further analysis, based on each disaster-related objective.

The results show that farming actors were not included in any pre-eruption coordination by the police, did not perform any pre-event disaster-related activities specific to the pending EFJV eruption due to limited knowledge of the risk of an eruption, but did respond to the eruption. An analysis of the information shows that risk analysis, mitigation and preparedness activities performed by farming actors before the eruption could have improved the response of the farming actors and thus better addressed the needs of farmers.

## 2 Method

The method involves four steps (Fig. 1). First, a livelihood-disaster perspective is developed (Sect. 2.1). The perspective is a combination of a livelihood and disaster perspective. The former is based on the SLF and the latter on the DFM objectives. The second step is identifying data sources for each component of the livelihood-disaster perspective in relation to farming, Eyjafjallajökull, and the 2010 EFJV eruption (Sect. 2.2). The third step is to extract relevant information from the data sources, thus presenting the farming-EFJV eruption perspective (Sect. 3). The final step is analysing the information in Sect. 3 for each DFM objective (Sect. 4).

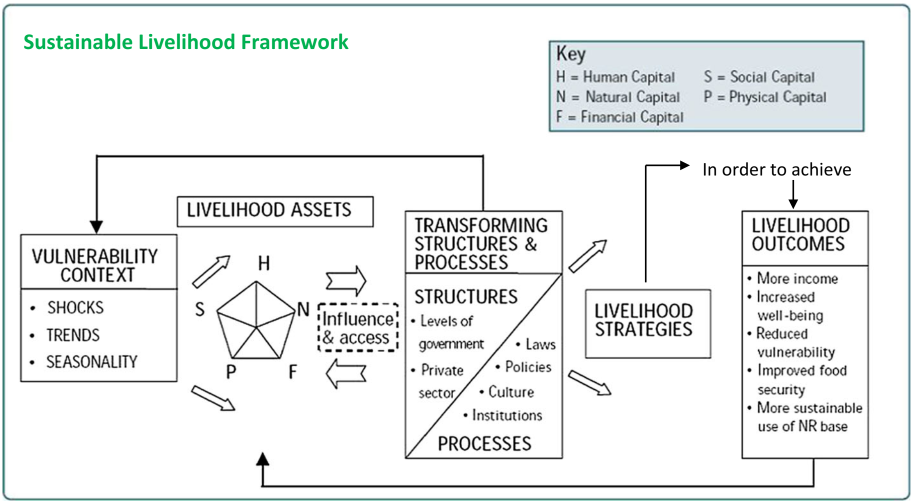



**Fig. 2** The Sustainable Livelihoods Framework (Based on Fig. 1 DFID 1999)

## 2.1 Livelihood-disaster perspective development

### *2.1.1 Livelihood perspective*

The Sustainable Livelihoods Framework (SLF) (DFID 1999) is used to outline a livelihood perspective. The SLF "presents the main factors that affect people's livelihoods and typical relationships between these". The "aim is to help stakeholders with different perspectives to engage in structured and coherent debate about the many factors that affect livelihoods, their relative importance and the way in which they interact". The framework captures how people's decisions on their livelihood are influenced by regulatory opportunities and restrictions that are produced by transforming actors, and the vulnerability context within which they live.

The SLF consists of five main components (see Fig. 2): (1) outcomes of livelihoods, (2) strategies to reach these goals, (3) livelihood assets (human, natural, physical, financial and societal), (4) transformation structures (hereafter termed actors as the study is limited to actors and their activities) and policies affecting the assets and, finally, (5) issues of vulnerability, such as shocks (including natural disasters), monetary trends and changing seasons.

The SLF allows for the perspectives of numerous actors that all relate to livelihood and thus create a general livelihood perspective. The SLF defines actors by types of organizations "that set and implement policy and legislation, deliver services, purchase, and trade and perform all manner of other functions that affect livelihoods". Table 1 (extracted from DFID 1999) depicts actor types and levels, and various types of units for actor analysis. All of these help define actor perspectives.

Various disaster studies have used a sustainable livelihoods approach, such as Cannon et al. (2005) (reducing social vulnerability from a development agency perspective), Twigg (2004) (project cycle approach from a primarily humanitarian and development agency perspective) and studies specifically on volcanic risk (see overview presented in Kelman and Mather 2008). Odero studied the SLF (2006) and suggests that relevant, accurate and timely information be added as the sixth asset. This is a key aspect of this study.

### *2.1.2 Disaster perspective*

The disaster perspective is presented through a set of disaster-related objectives associated with Disaster-Function Management (DFM) (see Table 2). DFM is derived from

**Table 1** Actor categories and aspects of analysis (DFID 1999)

| Type | Level | Analysis |
|---|---|---|
| Public sector | Political (legislative) bodies at various governmental levels from local to national<br>Executive agencies (ministries, agencies)<br>Judicial bodies (courts)<br>Parastatals/quasi-governmental agencies | Legal/constitutional basis, authority and jurisdiction (including degree of centralization)<br>Membership/ownership structure<br>Leadership/management structure<br>Objectives and activities<br>Financial basis (sustainability)<br>Geographic location/extent |
| Private sector | Commercial enterprises and corporations<br>Civil society/membership organizations (of varying degrees of formality)<br>NGOs (international, national, local) | |

**Table 2** Disaster functions and objectives (Thorvaldsdottir and Sigbjörnsson 2014)

| No. | Functions | Objectives |
|---|---|---|
| 1 | Disaster risk analysis | To understand disaster risk, its components and context |
| 2 | Disaster risk mitigation | To measurably reduce known disaster risk |
| 3 | Operational preparedness | To prepare operations for dealing with future disasters |
| 4 | Impact operations | To react to damaging processes prior to, during and after impact |
| 5 | Rescue operations | To save the lives of those caught in damaging processes |
| 6 | Relief operations | To provide temporary relief of suffering to those affected |
| 7 | Recovery operations | To implement final measures to bring a community back to normalcy |
| 8 | Systematic learning | To systematically learn from recent events and implement changes |

Comprehensive Emergency Management, which was defined in 1979 (NGA 1979) as the management of disaster-related activities in four phases: mitigation, preparedness, response and recovery. However, since then the concept of phases as the appropriate approach to disaster management has been challenged (Neal 1997; McEntire et al. 2002) and the idea of functions or functional areas suggested (McEntire et al. 2002; Quarentelli 1996). Thorvaldsdottir and Sigbjörnsson (2014) outline how current scientific and practical knowledge has surpassed the four-phase framework and describe why and how phases are replaced by objectives for management purposes. DFM is set within classical management theory, governed by "management by objectives", and has been introduced as a contribution towards a new paradigm for addressing disaster-related management. Classical management theory states that "management by objectives", as a concept, is an integrated management system to manage an organization by aligning the entire managerial effort with specific performance goals (Ghuman 2010). Applying "management by objectives" to coordination creates a coordination process that meets chosen objectives, thus giving the process a clear focus.

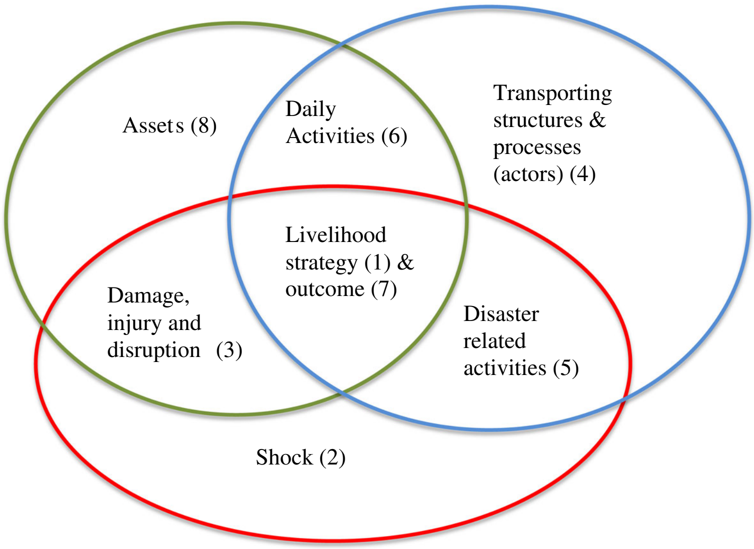



**Fig. 3** Venn diagram for livelihood-disaster perspective

### *2.1.3 Livelihood-disaster perspective*

The livelihood-disaster perspective is presented by a Venn diagram consisting of three overlapping rings (Fig. 3). First, the five basic components of the SLF are placed in the diagram. The Livelihood Strategies and Livelihood Outcomes are placed at the centre, representing the desired and actual outcomes when adopting the SLF. The three remaining components, Assets, Shock, and Transporting Structures and Processes (actors), are placed in each of the outer rings. The overlaps are filled with aspects that link the two basic SLF components on either side. The linking components are as follows:

- *Actor daily activities,* linking Transporting Structures and Processes (actors) and Assets, addressing how actors manage assets.
- *Disaster-related activities,* linking Transporting Structures and Processes (actors) and Shock, addressing how actors manage shock-related issues.
- *Damages, injury and disruptions*, linking Assets and Shock. When addressing future disasters, the link is *vulnerability to* damages, injury or disruptions. When addressing actual disasters, the link is *actual* damages, injury or disruptions

## 2.2 Data sources

The following data sources were identified as relevant to the respective components in Fig. 3 for the farming-EFJV context:

1. Farming livelihood strategies
    a. Report on government farming strategy (Jóhannesson and Agnarsson 2005)
    b. Discussions with a teacher at the Agricultural University of Iceland
    c. Discussions with a farmer in the affected area
2. Shock (volcanic ash)
    a. Farming next to a volcano, literature-based discussion
    b. Literature survey for an overview of volcanic activity in Iceland
    c. Literature survey for an overview of the EFJV hazard and eruption 1991–2010
3. Damages, injuries and disruption
    a. Literature survey on the vulnerability of physical and natural farming assets due to ash
    b. Actual damages, injuries and disruption described in Farmers' Reconnaissance Report (2010)
4. Actor identification and classification
    a. Farmers' Reconnaissance Report (2010)
    b. SLF actor classification (Table 1)
5. Actor daily activities
    a. Daily objectives stated on actor websites
6. Actor disaster-related activities
    a. Interviews with actors

   b. Literature on the EFJV before and after the eruption
   c. EFJV activity reports acquired from websites
   d. Act on Civil Protection

7. Farming livelihood outcome (situation in 2010)

   a. Farmers' Reconnaissance Report (2010)

8. Farming assets

   a. Farming assets are apparent in the text, e.g., animals, buildings, land, but they are not presented here in a separate discussion.

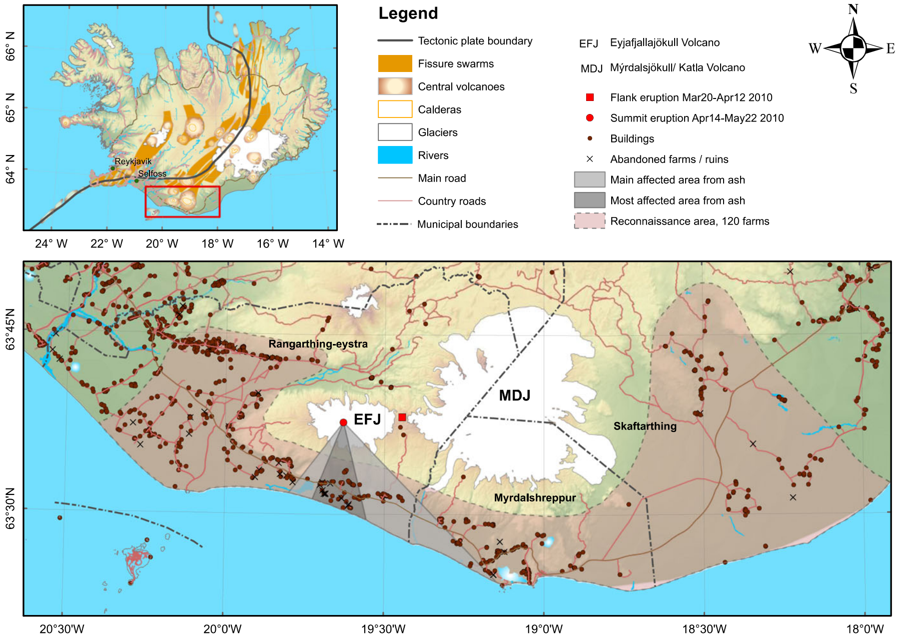
### *2.2.1 Farmers' Reconnaissance Report 2010*

The key source of information about the status of farmers and their farms and for determining relevant actors is a report from a reconnaissance (abbreviated recon) performed 11–12 May 2010, approximately 4 weeks after the explosive episode of the eruption began (Farmers' Recon Report 2010). The Farmers' Association, The Agricultural Association of South Iceland and other regional farmers' associations, and the Ministry of Agriculture organized the recon. Its purpose was to bring relevant actors together to share information and ideas, collect information, maximize the use of resources and plan assistance to the affected farmers (Farmers' Recon Report 2010). The first day was spent on site visits and the second on planning and developing recommendations. Approximately 35 people were divided into 2–3 people teams and visited approximately 120 farms (see Fig. 4). The organizers decided on the following questions to ask during the site visits:

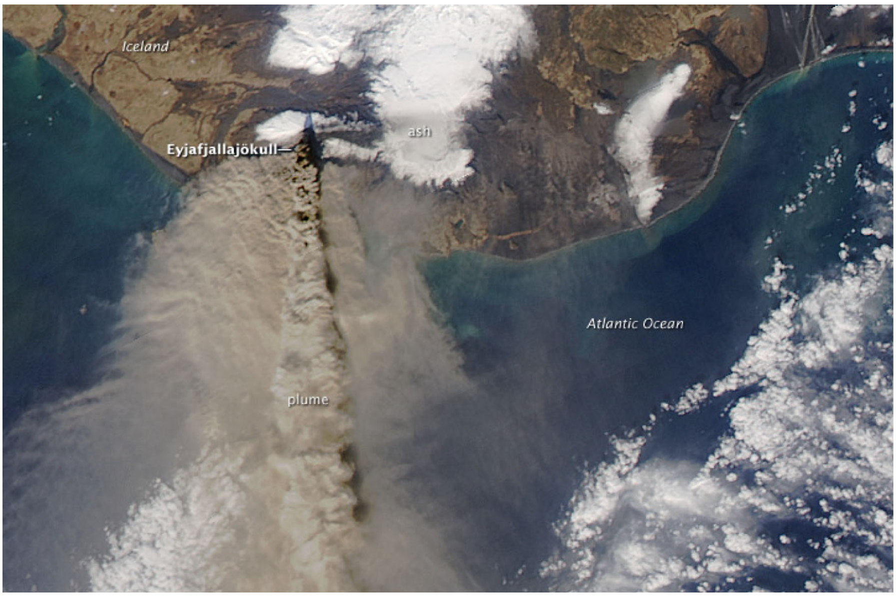
1. How many animals are on the farm (cows, sheep, horses)?
2. What is the housing need for animals (cows, sheep with lambs, horses)?
3. Is there sufficient feed and (uncontaminated) running water for all the animals?
4. For how many days will the current quantity of hay last?
5. Has the farmer secured extra hay, if needed?
6. If the eruption ends within 15 days, how many animals need to be transported, and how much hay is needed?
7. If the eruption continues into the summer, how many animals need to be transported, and how much hay is needed?
8. What type of solutions does the farmer recommend?
9. What damage has occurred that will be insured by the Farmers' Insurance Fund?
10. Is extra manual labour required?

When asked what prompted the recon, the organizers stated they had gradually realized their own lack of understanding of the magnitude of the problems amongst farmers. Four explanations are stated here. First of all, questions arose about housing and feeding sheep. It was now spring so sheep were inside in pens, and lambing season was approaching. Sheep are usually kept inside during the winter months and put outside 3–4 days after their lambs are born. Then, after all lambs are born, the ewes, lambs and rams are driven to the highlands for the summer, and in the autumn the sheep are collected and the lambs slaughtered. The ash could hinder farmers putting the sheep outside and render the highlands unusable. This meant that the farmers had to somehow cope with an expanding sheep population inside the pens, causing overcrowding. Second, field staff members assisting the affected farmers, for example, from South-Agri, were beginning to show

**(a)**




**(b)**




fatigue and needed support. A multi-organization recon would provide an overview of the situation and generate ideas on how to support them. Third, there was concern over the possible impact if the wind changed direction. The winds had been northerly; if they

◀**Fig. 4** The area of reconnaissance **a** Location of 120 farms visited during the 11–12 May 2010 reconnaissance. The Icelandic volcanic system and plate boundaries are depicted in the map in the upper left corner. The rectangle in this map shows the reconnaissance area. The main figure is an enlarged view of this area. All the buildings in the recon area are farm buildings. **b** Ash from Eyjafjallajökull Volcano, 17 April 2010. NASA image by Jeff Schmaltz, MODIS Rapid Response Team. Source: http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=43690, extract 6 May 2014

changed to easterly winds, new farming areas would be affected. The organizers wondered what problems this would create, and how they should respond to assist farmers. A recon would allow organizers to understand the problems and concerns of the farmers (i.e., obtain the farmer's perspective) and seek their opinion on possible solutions. Finally, the organizers wanted to support the affected farming population by showing their concern. The eruption was still going on, and the end of the eruption could not be predicted.

### *2.2.2 Interviews*

Interviews (Aug–Nov 2013) provided information about the activities of the actors in respect of the eight objectives of DFM as related to EFJV 1991–2013. A representative of each actor was asked eight questions; one question on each of the eight DFM objectives: *what activities did you perform towards this objective in relation to the EFJV hazard/eruption?* Discussions with a teacher at the Agricultural University of Iceland and with a farmer in the affected area were also used to generate information.

## 3 Farming-EFJV perspective

This section presents extracts from the data sources listed in Sect. 2.2 relevant for farming in the vicinity of the EFJV. The tables and figures created herein relate to the Venn diagram in Fig. 3, as depicted in Fig. 5.

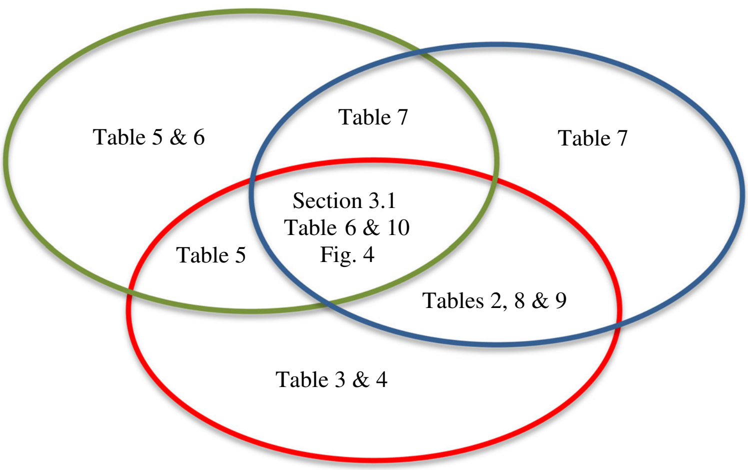



**Fig. 5** Information defining a farming-disaster coordination perspective in Iceland regarding the 2010 EFJV eruption

## 3.1 Farming livelihood strategies

"Livelihood strategies" is the term used to designate the range and combination of activities and choices that people make/undertake in order to achieve livelihood goals (DFID 1999). Livelihood goals are broader than a pure business goal. For example, investments, such as in technology, may be for the purpose of increased production to increase income or to ease physical labour and shorten working hours, leading to healthier and longer lives, giving opportunities to spend time on other things, whether farming-related or leisure (Jóhannesson and Agnarsson 2005). Livelihood goals are therefore affected by an individual's motive for choosing a particular livelihood. Farming is the business of growing crops and/or raising livestock (Jóhannesson and Agnarsson 2005). There are many motives for choosing farming, such as family tradition, wanting to be your own boss, desire to work with animals or desire to work with machinery (Gislason 2013). Attachment to the land can also influence choosing farming as a livelihood (Eyvindsson 2013). A farming strategy is based on decisions on a variety of livelihood variables that characterize farming, including (Jóhannesson and Agnarsson 2005):

- Type of production
- Type of livestock
- Proximity to market
- Level of technology
- Level of debt

The farming market is unique in that its products are seen as essential for human survival. This is reflected in product demand being relatively insensitive to market price (Jóhannesson and Agnarsson 2005). Government strategy in Iceland regulates to some degree both the supply and price of these products through various regulatory tools, such as production quotas and subsidies, and includes ensuring food security on the island and avoiding total migration to the capital (Jóhannesson and Agnarsson 2005). Government agencies monitor animal welfare and production and control the risk of disease by establishing control areas. Live animals, hay and other farm products may not move between these areas. The 2014 annual meeting of the Farmers' Association concluded that the association should work with the government on a long-term farming strategy in association with the specialized farming organizations (for cattle, eggs, pig farming, etc.) (*Bændabladid* Newspaper 2014), showing farmers' interest in influencing government farming strategy.

## 3.2 Shock (volcanic ash)

### *3.2.1 Volcanic activity in Iceland*

Iceland is one of the most active and productive volcanic regions in the world. Its eruption frequency is up to 20 events per century (Thordarson and Höskuldsson 2008). Eruptions are broadly grouped into effusive eruptions, where over 95 % of the erupted magma is lava, explosive eruptions if more than 95 % of the erupted magma is tephra and mixed eruptions if they include tephra but less than 95 % (Thordarson and Larsen 2006). Explosive events in Iceland are dictated by sub-glacial events and are more common than effusive activity or mixed eruptions (Thordarson and Larsen 2006). A summary of verified eruptive events is presented in Table 3. A total of 2400 eruptions have been identified from post-glacial times (last 11,000 years). In historical times (last 1100 years), a total of 192

**Table 3** Volcanic activity in Iceland, verified events

| Period | Eruptive events | Explosive (%) | Effusive (%) | Mixed (%) | Reference |
|---|---|---|---|---|---|
| Last 11,000 years | 2400 | ~77 | ~23 | – | Thordarson and Höskuldsson (2008) |
| Last 1100 years | 159 Verified single eruptions | 78 | 9 | 13 | Thordarson and Larsen (2006) |
| | 13 Fires | – | 62 | 38 | |

single eruptive events have been verified, based on volcanic products, and 33 were mentioned in oral accounts. In addition, 13 fires (multiple events) lasting for months or years have been verified in historical accounts.

Four volcanoes or volcanic systems have been most active in historical times: Katla Volcano under the Mýrdalsjökull icecap (21 eruptions), Grimsvötn/Laki (~70), Hekla (23 eruptions) and Bardarbunga/Veidivötn (23 eruptions) (Gudmundsson et al. 2008). Both Hekla and Katla Volcanoes have produced ash layers over 20 cm thick over the area surrounding Eyjafjallajökull (Fig. 3 in Gudmundsson et al. 2008, reprinted as Fig. 6). Figure 6 shows "areas that may receive over 20 cm of tephra fall in major explosive eruptions indicated with circles around volcanoes or fissure swarms, where explosive activity is common or the dominant mode of activity. The radius of each circle is defined as the distance to the 20-cm isopach along the axis of thickness for the largest historical and prehistoric explosive eruptions of each volcano. Also shown are populated areas and the main route, Highway 1. The volcanic zones are shown with a shade of grey" (Gudmundsson et al. 2008).

### *3.2.2 Eyjafjallajökull volcano*

Eyjafjalla*jökull* (*glacier*) is in South Central Iceland in the Eastern Volcanic Zone. Prior to the 2010 eruption, the volcano is believed to have erupted four times. The most recent was in 1821–1823. Chronicles provide relatively detailed accounts of a small intermittent explosive eruption, producing ash levels harmful to livestock (Larsen 1999). The ash led to considerable fluoride poisoning and negatively impacted farming activities in general, including reduction in livestock (Larsen 1999). Historical accounts indicate that there may have been an eruption in 1612 or 1613 (Vetter 1983) although the physical evidence of ash is inconclusive (Larsen 2013), and it may have been its more active neighbour Katla Volcano that the accounts refer to Sturkell et al. (2003). Dugmore et al. (2013) have recently identified and dated floods that verify flank eruptions in ca. 920 AD and in the sixth to seventh century. Dugmore et al.'s work is referenced as "unpublished results" in Gudmundsson et al. (2005), so it was known prior to the 2010 eruption.

A chronological outline of key geological and scientific events from 1991 to 2010 and post-eruption activities, based on Sigmundsson et al. (2010), Gudmundsson et al. (2010, 2012) and other references, is presented in Table 4. The recognition of geophysical precursors to volcanic activity is a primary challenge in volcanic monitoring (Vogfjörd et al. 2005). Prior to the 1990s, only about a handful of earthquakes associated with the Eyjafjallajökull volcanic system had been detected (Pedersen and Sigmundsson 2006); after that the situation gradually changed. The 2010 eruption was the culmination of two decades of intermittent volcanic unrest, providing ample precursors, many of which were

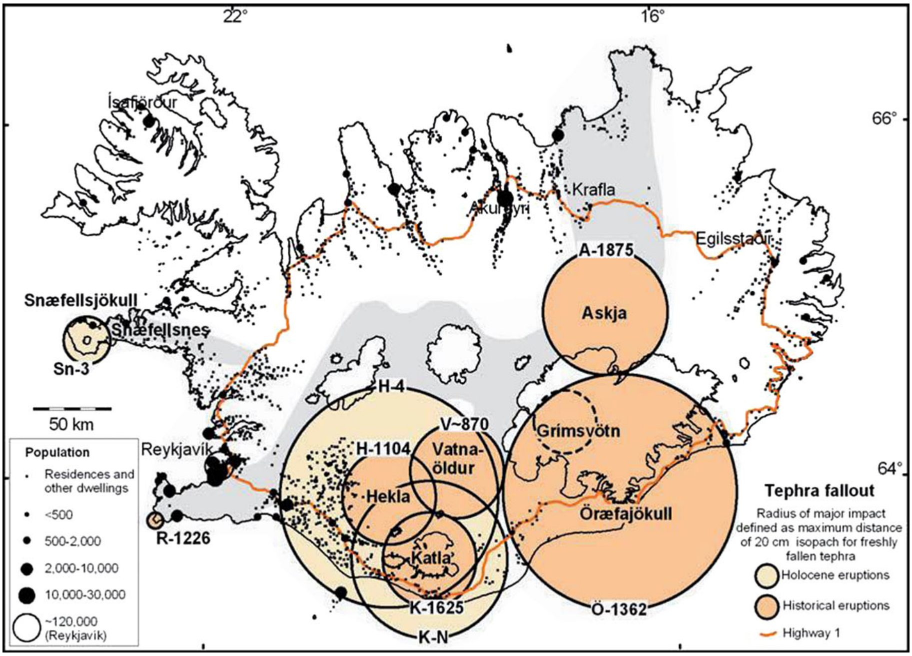



**Fig. 6** Ash hazard map from 2008 showing 20-cm isopach radius (Fig. 3 in Gudmundsson et al. 2008)

captured by scientists. An effusive flank eruption began on 20 March, ended on 12 April and caused no damage (Gudmundsson et al. 2010). Increased seismic activity was noted by seismometers in EFJV at 2300 local time on 13 April. The summit eruption commenced at 0115. A plume was visible in the early hours of the 14th, and the first signs of glacial flooding were seen at 0650 at a gauging station (Gudmundsson et al. 2010). Concern arose about health risks from fallout, because ash can transport acids as well as toxic components, such as fluoride, aluminium and arsenic (Gislason et al. 2011). The summit eruption lasted 39 days, till 22 May. Persistent north-westerly winds transported the ash towards the southeast (Gudmundsson et al. 2012). The intensity of tephra fallout varied throughout the eruption. As explained by Gudmundsson et al. (2012, Fig. 4, reprinted as Fig. 7), Fig. 7 shows isopach maps (thickness in cm) of tephra deposition on land (a) during the first 3 days of the first explosive phase, erupting from a water-filled vent (14–16 April), (b) during the second part of the first explosive phase (17 April until early 18 April) and (c) total fallout on land in the eruption (14 April–22 May) and estimated fallout thickness (dotted lines) to the south and south-east of Iceland. Based on Fig. 7, the entire ash fallout in the recon area is estimated to be less than 5 cm thick over the main area. Less than 10 cm were measured at the foothills of the volcano (Gudmundsson 2014).

### 3.3 Damage, injury and disruption

Large explosive volcanic eruptions can potentially distribute heavy ashfall across large areas of agricultural land (Wilson et al. 2011a, b). Farming near an active volcano has both positive and negative aspects (Kelman and Mather 2008). Volcanic soils are often physically and chemically suited for growing crops, and long periods between eruptions

**Table 4** Geophysical events of EFJV from 1991 to 2013

| Year/date | Geophysical events | Reference |
|---|---|---|
| 1991 | The first signs of unrest under EFJV started near the end of 1991. | Sturkell et al. (2003) |
| 1993 | Gas monitoring | Gislason (2000) |
| 1994 | The activities starting in 1991 peaked with an earthquake swarm in 1994. | Sturkell et al. (2003) |
| 1994 | The 1994 deformations were observed using interferometric synthetic aperture radar (InSAR). | Pedersen and Sigmundsson (2004) |
| 1999 | Earthquake swarm. Deformation detected. The results interpreted to mean intrusions into an opening of a narrow magma channel at depth, feeding into a sill at a depth of 4–6 km | Pedersen and Sigmundsson (2006) |
| 2000 | In 2000, research indicated that a magma chamber could be at a shallow depth | Gislason (2000) |
| 2000–2009 | During the period 2000–2009, earthquakes were measured intermittently at rates of 1–4 events per month, whilst deformation remained negligible | Vogfjörd et al. (2009) |
| 2009 | By 2009 scientists had identified, through seismic analysis, a pipe-like structure under the volcano, mapping the route of magmatic intrusions through the crust | Vogfjörd et al. (2009) |
| 2010/Jan-Mar | In January 2010, deformation was again detected, and the level of seismicity increased to several earthquakes a day. These changes marked the onset of magma flow into the roots of the volcano, culminating late in the evening of 20 March 2010 in the opening of a short effusive fissure eruption on the volcano's flank | Sigmundsson et al. (2010)<br>Hjaltadottir and Vogfjord (2010) |
| 2010/Mar 20 | A short effusive fissure eruption began on the flank of the volcano at Fimmvörduháls Ridge around 2330 UTC on 20 March | Gudmundsson et al. (2010) |
| 2010/Apr 12 | Flank eruption on Fimmvörduháls Ridge ended on 12 April, causing no damage | Gudmundsson et al. (2010) |
| 2010/Apr 13 | Increased seismic activity started at 2300 local time, lasting a few hours | Gudmundsson et al. 2010 |
| 2010/Apr 14 | Summit eruption commenced at 0115, a plume visible in the early hours and the first signs of glacial flooding seen at 0650 at a gauging station. The eruption plume (tephra, gases and chemicals) reached a height of almost 10 km the first day. Lightning was seen in the ash cloud | Gudmundsson et al. (2010) |
| 2010/Apr 14–15 | Intense fallout occurred on 14–15 April | Gudmundsson et al. (2012) |
| 2010/Apr 14–May 22 | Tephra fallout during the entire eruption of April 14 to May 22 estimated less than 5 cm thick in the recon area (see Fig. 4c in reference) | Gudmundsson et al. (2012) |
| 2010/Apr 14–26 | Lava flowed for 12 days, spilling north into Gígjökull Glacier Lake | Gudmundsson et al. (2010) |
| 2010/Apr 15 | Absolute darkness in the middle of the fallout zone at 12:45 PM | Gislason and Alfredsson (2010) |
| 2010/Apr 17 | Tephra fallout caused total darkness for 20 h | Gudmundsson et al. (2012) |

**Table 4** continued

| Year/date | Geophysical events | Reference |
|---|---|---|
| 2010/May 19 | After only 10 mm of rain fall, a lahar occurred on the southern slope of Eyjafjallajökull, caused by remobilization of freshly fallen tephra on the glacier<br>The flow travelled along the Svadbælisá River gorge in an erosive phase but transformed into a depositional phase as it reached the lowland. The lahar inundated an area of 0.4 $km^2$ with a 30 cm thick deposit, mainly on the river fan. Once deposition began in the lowland, the flow became gradually richer in water and poorer in ash, eventually carrying only the finest particles to the sea. The flow caused some damage to farmland and to an aqueduct | Thorkelsson (2012) |
| 2010/May 22 | The eruption ended on 22 May, lasting 39 days. The summit eruption was deemed of modest size: VEI 3, erupted material $4.8 \pm 1.2\ 10^{11}$ kg (20 % lava and water-transported tephra and 80 % airborne tephra), 3–10 km high plumes; ash grain size mostly fine or very fine; about 50 % of it fell in Iceland | Gudmundsson et al. (2012) |
| Post-eruption | The EFJV eruption resulted in huge dust emissions during the time the ash was still unstable, causing poor air quality over 100 km away | Arnalds (2010) |
| Post-eruption | After the eruption, volcanic ash deposited in the Eyjafjallajökull region was remobilized by strong wind. Re-suspended ash occasionally resulted in significantly increased concentrations of airborne particles and reduced visibility | Thorkelsson (2012) |
| Post-eruption | Dust storms were frequent in the years following the eruption, causing severe damage to ecosystems in areas with sparse vegetation, whilst more resistant systems, such as woodlands, stabilized the ash | Arnalds et al. (2013) |

make agriculture common in volcanic regions (Cronin et al. 1998, Wilson et al. 2011a, b). The negative aspects involve the susceptibility of assets, people and farming processes to damage, injury and disruption, respectively, due to eruptions. The problems the farmers faced in Iceland in 2010 were due to ashfall and remobilized ash. The nearest farms were roughly 20 km from the summit.

### *3.3.1 Pre-eruption knowledge on vulnerability*

A literature survey of papers published before the 2010 EFJV eruption was done to gain understanding of the information available prior to the eruption on vulnerable conditions for farming assets due to ash (see Table 5). Two of the papers in Table 5 are published after the eruption: one relays information available before the eruption regarding lack of visibility during an eruption (Bird and Gisladottir 2012) and the other describes an eruption in 1991 (Wilson 2011a, b). The papers discuss the vulnerability of mainly natural and physical farming assets, such as livestock, farming processes, buildings, infrastructure, utilities and mechanical equipment. More recent papers illustrate the ever-expanding knowledge of volcanic vulnerability (see, for example, Wilson et al. 2012a, b and Magill et al. 2013).

Impacts from past eruptions provide insight into the vulnerability associated with farming close to volcanoes (e.g. Kelman and Mather 2008, Lebon 2009). All forms of agricultural production are vulnerable to the physical and chemical effects of volcanic

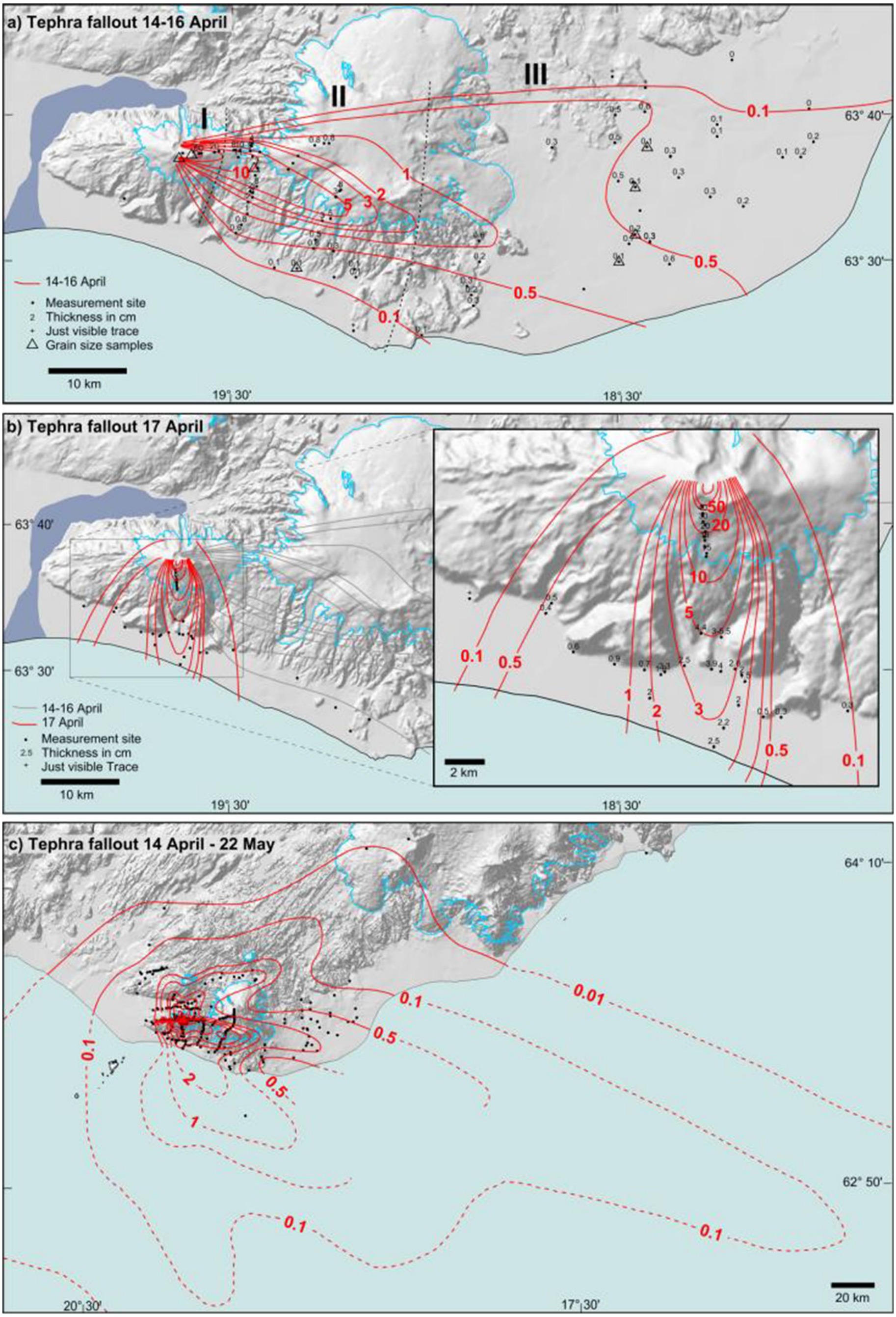



**Fig. 7** Ash distribution from the 2010 Eyjafjallajökull eruption (Fig. 4 in Gudmundsson et al. 2012)

**Table 5** Farming vulnerability due to volcanic ash

| References | Content | Asset category |
|---|---|---|
| Kristinnsson et al. (1997) | Fluoride poisoning of sheep (diarrhoea, loss of appetite and general prostration, dental fluorosis at different concentration levels) | Natural |
| Cronin et al. (1998) | Livestock starvation when pastures were covered by tephra. Chemical impact of tephra on soil and pastures, and their effect on grazing livestock | Natural |
| Spence et al. (1999) | Building damage (collapse, roof failure) | Physical |
| Arnalds et al. (2001) | Wind erosion and loss of soil and ecosystems due to volcanic ash and sands | Natural |
| Annen and Wagner (2003) | Damage to farmlands, buildings, roads, bridges, forest fires and interruption of agricultural activities | Physical, natural |
| Spence et al. (2004) | Resistance to lateral pressures of glazed openings; shuttered openings; masonry wall panels; and reinforced concrete frame buildings | Physical |
| Wilson and Cole (2007) | Dairy shed, milking machine, electrical supply and distribution, water supply and distribution, tractors and other farm vehicles, farm buildings (hay sheds, pump sheds, etc.), milk tanker access to farm and critical needs of dairy cows and farm to keep milking | Physical and natural |
| Wilson et al. (2010) | Blocked or damaged water delivery systems due to sedimentation of irrigation ditches and potable water ponds, turbidity-induced abrasion of sprinkler nozzles and water pumps, and damage to electric pumps (by ash on air intakes) | Natural |
| Bird et al. (2010) Bird and Gisladottir (2012) | Darkness during daytime | Natural |
| Wilson et al. (2011a, 2011b) | Livestock deaths due to pasture burial by ashfall and ongoing suppression of vegetation recovery. Livestock impacts: gastro-intestinal impacts, tooth abrasion, dehydration, immobilization, and blindness. Vegetation and soil impacts: effect on soil fertility, effects on water retention. Ongoing damage to crops from wind-blown ash. Changes to soil properties increased irrigation and cultivation requirements. Long-term farm abandonment. Farms with natural advantages and greater investment in capital improvements led to greater damage potential initially (at least in cost terms), but ultimately provided a greater capacity for response and recovery. Better soils, access to technological improvements, such as cultivation tools, irrigation and wind-breaks, were advantageous. Government agencies' dissemination of information for appropriate farm management responses, ash chemistry analysis, evacuations and welfare, and technical and credit assistance to facilitate recovery | Natural |

ashfall, including vegetation, soils, animal health, human health and infrastructure (Wilson et al. 2011a, b). The impact of eruptions in Iceland includes people being killed (by drowning, lightning and $CO_2$ suffocation), livestock deaths (by tephra fall leading to lack of access to feed and fluorine poisoning) and crop damage from ash coverage, leading to farm abandonment and famine. Heavy tephra fall in past Katla eruptions has been known to obstruct visibility (Bird et al. 2010), causing total darkness during the day (Bird and Gisladottir 2012).

Fluoride is a potentially toxic element for people and animals and can severely impact sheep through diarrhoea, loss of appetite and general prostration and dental fluorosis at different concentration levels (Kristinnsson et al. 1997). The degassing of magma chemicals produces fluorine, sulphur and chlorine in the atmosphere (Thordarson et al. 1996). Soluble fluorine can be chemically adsorbed on the surface of tephra particles (Oskarsson 1980) and thus transported with the ash. Fluorine can also be transported by water due to leaching from tephra and gas particle disposition. Fluorine concentration has even been measured to rise 5 days after an eruption ended due to the melting of polluted snow and leaching of pollutants from volcanic ash into a river discharge area during a rainstorm (Gudmundsson et al. 1992). Fluoride can contaminate open drinking water sources. Outbreaks of fluoride toxicosis (fluorosis) in farm animals have repeatedly been observed in Icelandic sheep when pastures and drinking water have become contaminated with fluoride from volcanic eruptions (Kristinnsson et al. 1997), for example, from Hekla and Laki eruptions (Gudmundsson et al. 2008), and EFJV (Larsen 1999).

According to Wilson et al. (2011a), the impacts and consequences of remobilized ash were seldom examined prior to the EFJV eruption. However, the seriousness of remobilized ash was already identified following an eruption of Vulcan Hudson in Patagonia in 1991 (Scasso et al. 1994). Remobilization is related to wind erosion. Problems associated with sand and dust production from volcanic eruptions, wind erosion and loss of ecosystems in Iceland are well known (Arnalds et al. 2001). Iceland has about 22,000 $km^2$ of sandy deserts that are a major source of atmospheric dust. Icelandic dust is mostly basaltic volcanic glass, which is rather unique for global dust sources (Arnalds et al. 2001). The sandy areas have black surfaces due to their basaltic origin. The sand originates largely from glacial margins, glacio-fluvial deposits and volcanic eruptions, but also from sedimentary rocks (Arnalds 2010). Wind erosion has been extensively studied in agricultural fields, but knowledge of field conditions and wind erosion rates of fresh volcanic deposits under severe wind conditions is limited (Arnalds et al. 2013).

### *3.3.2 Actual damages, injuries and disruption*

The main and most affected areas, according to the recon, are depicted in Fig. 4a, corresponding to the ash plume in Fig. 4b. There were less than 20 farms in the main affected areas, and less than 10 of these were in the most affected area (see Fig. 4a). The issues raised by farmers during site visits are divided into four categories (see Table 6): coping strategies, constraints to the coping strategies, complaints about the response and concerns over issues that they did not know how to deal with. The main factors amongst farmers, according to the recon, were questions related to the natural assets (air quality, the impact of chemicals on pastures and fodder, etc.), physical (housing of animals, etc.), farming processes (lambing, fencing, temporary pastures, etc.) and financial concerns. Financial worries included the overall impact of the damages and disruption on farmers' ability to pay debts. For example, lambs are normally slaughtered in the autumn, but if the situation called for early slaughtering, lambs would be smaller than at the normal slaughtering time, and farmers were concerned about being compensated for such losses. Farmers' Insurance Fund coverage was also a concern at the time of the recon. The Fund determines compensation on a case-by-case basis (i.e., per eruption, earthquake, snowstorm, etc.), depending on the typical types of damage each time. At the time of the recon, farmers were still uncertain about which types of damages would be compensated.

**Table 6** Farmers' viewpoint collected during recon

| Category | Issue |
|---|---|
| Coping strategies | Some farmers kept ewes inside after lambing to shelter them from the ash. This could only be a temporary solution as it led to overcrowding in pens as the number of lambs increased. Therefore, finding additional shelter for the animals was an issue. Furthermore, keeping the animals inside created a need for extra feeding. Some farmers used last year's hay stock for feed |
| | Some farmers fenced off unspoiled pastures to create new grazing areas, which required fencing |
| | Farmers stated that they were coping with regard to water for the animals, saying there was plenty of natural running (uncontaminated) water available |
| Constraints | The ash and dust in the atmosphere led to lack of visibility, breathing and eye problems and other health issues. It also limited the ability of farmers to work. It was also a problem for the animals |
| | In some cases, animal evacuation was ruled out (120 Galloway bulls and horses that were roaming free "here and there", which were difficult to round up) |
| Complaints | Lack of information about the fluoride tolerance of sheep and lambs |
| | Lack of sampling to assess chemical threats to animals and fodder |
| | Authorities did not view the dust in the atmosphere as the same health hazard that farmers did and were not taking the hazard seriously |
| Concerns | Are fields and pastures suitable for grazing? |
| | Should the farmers keep the sheep at the farm, should they drive the sheep to normal summer pasture or create temporary pastures out of the ash-affected area? What is the condition of summer pastures? If the eruption stops soon, and it rains, then the situation will be better, but what if the eruption continues? If the farmers choose to create a temporary pasture, which areas are going to be restricted by the government agencies that decided disease control areas? Who will pay for fencing and transport to temporary pastures? |
| | If cows are transported away from the farm, who will milk the cows and tend to the animals? Who will pay for the transport? |
| | Is it feasible to distribute fertilizer and sow? How much time do I have to find out the answer before it is too late? |
| | Will the autumn harvest be affected by ash on the soil and vegetation? If so, will I have enough hay for the winter? If not, where do I get more hay? Do government agencies set restrictions, due to disease control areas, on the areas in the country where I can buy hay? |
| | Can I get assistance with fencing, both labour and materials? |

## 3.4 Actor identification

The Farmers' Recon Report mentions 11 institutions. Each of these was by default an actor relevant to the study, since they were either directly involved in the recon or referred to as an actor of relevance in the report. Each actor is characterized in Table 7 by name, type (public or mixed public and private) and level (executive or/and civil organization, both national and local). The Farmers' Association, The South-Agri and other regional farmers' associations, and the Ministry of Agriculture organized the recon. Representatives from the Food and Veterinarians Authorities, the Agricultural University of Iceland, police authorities, and the Rangarthing Eystra Municipality participated in the data analysis and development of recommendations. The Land Conservation Authorities, the Farmers' Insurance Fund, the Icelandic Catastrophe Insurance and the Directorate of Labour are mentioned in the report.

**Table 7** Actor characterization

| No. | Actor | Type | Level | Description in relation to daily objectives | Relevance as actor |
|---|---|---|---|---|---|
| 1 | Ministry of Agriculture | Public | Executive National | The Ministry is responsible for research on and supervision of agriculture, commercial forestry, import and export of animals and plants, food inspection and food research | Direct farming actor |
| 2 | Farmers' Association of Iceland | Public and private | Executive and Civil Organization National | The Farmers' Association is an advocate for farmers. It works towards progress and prosperity within agriculture. It strives to improve conditions, provide professional guidance, publications and information and do projects for the government | Direct farming actor |
| **3** | South-Agri: Agricultural Association of South Iceland | Public and private | Executive and Civil Organization Local | The Agricultural Association of South Iceland is an organization of agricultural societies and clubs in South Iceland. South-Agri operates for the benefit of individual farmers. Its aim is to increase agricultural efficiency in the area and the prosperity of the members and clients | Direct farming actor |
| 4 | The Icelandic Food and Veterinary Authority | Public | Executive National | The Icelandic Food and Veterinary Authority is the competent authority in Iceland for food safety, animal health and welfare, control of feed, seed and fertilizers, plant health and water for human consumption | Direct farming actor |
| 5 | The Agricultural University of Iceland | Public | Educational National | The Agricultural University is an educational and research institution in the field of agriculture and environmental sciences. It focuses mainly on the conservation and sustainable use of land and animal resources, including traditional agriculture, horticulture and forestry, environmental planning, restoration sciences, rural development and sustainable development | Direct farming actor |
| 6 | Land Conservation Authority | Public | Executive National | The Land Conservation Authority is responsible for combating desertification, sand encroachment and other soil erosion, promoting sustainable land use and the reclamation and restoration of degraded land. The speed of erosion is magnified by volcanic activity and harsh weather conditions. The Land Conservation Authority is dedicated to the prevention of erosion and the reclamation of eroded land | Direct farming actor |

**Table 7** continued

| No. | Actor | Type | Level | Description in relation to daily objectives | Relevance as actor |
|---|---|---|---|---|---|
| 7 | Farmers Insurance Fund | Public | Executive and Civil Organization National | The State and the farmers own the Farmers' Insurance Fund. It compensates individuals and farming societies for various damages caused by natural disasters and animal diseases, in addition to what is covered by Iceland Catastrophe Insurance | Direct farming actor |
| 8 | Iceland Catastrophe Insurance | Public | Executive National | Iceland Catastrophe Insurance insures real estate against natural disasters. If building content is insured against fire, then it is also insured by this fund | Associated actor |
| 9 | Directorate of Labour | Public | Executive National | The Directorate of Labour is responsible for the management of the National Employment Service as well as the daily operation of the Unemployment Benefit Fund, the Wage Guarantee Fund, the Childbirth Leave Fund and payments to parents of children with long-term illness | Associated actor |
| 10 | Chief of Police | Public | Executive Local | Besides law enforcement activities, the district police are in charge of civil protection operations in the district during a "civil protection situation" | Associated actor |
| 11 | Rangarthing Eystra Municipality | Public | Executive Local | Manages the community, such as schools, cultural buildings, sports halls, planning and construction, roads, sewage, cold water systems, harbours, playgrounds, tourist sites, campsites and employment issues | Associated actor |

### 3.5 Actor daily activities and categorization

An actor's daily activity is inferred from their general objectives described on the website (see Table 7). The relevance of the actors to the study is based on the relevance of their daily objectives to a farming livelihood perspective and falls into one of the two following categories:

1. Direct farming actors: those working directly for, or with, farmers for the sake of livestock or production matters, at any level.
2. Associated actors: those who deal with farmers for reasons other than farming, influence farmers' lives and livelihoods, but are not involved in farming-related activities.

Seven of the 11 actors were direct farming actors (No. 1–7, Table 7). Five were on a public executive level, dealing with matters of government strategy, implementation and monitoring, government insurance companies and educational establishments. The other two were a national and a regional farmers' civil organization (Farmers' Association and

South-Agri), with executive roles, and were the main organisers of the recon. The Ministry of Agriculture is the highest ranking governmental farming actor. The ministry interacts with the national civil organization, which interacts with the local civil organization. Four of the 11 actors were associated actors (Nos. 8–11, Table 7). The Iceland Catastrophe Insurance provides insurance against natural disasters for buildings that have fire insurance; the Directorate of Labour deals with issues of unemployment and paid for temporary labourers to farmers and farming actors; the police deal with law enforcement and take charge in matters of Civil Protection; and the municipality manages community services and affairs.

## 3.6 Actor disaster-related activities

### *3.6.1 Interview summaries*

A narrative summary of the answers to the interviews is presented in Table 8. Not all actors are necessarily associated with all disaster-related objectives, e.g., the insurance companies in this study do not address life safety, resulting in no action towards objective #5.

For overview purposes, Table 9 shows the results in Table 8 coded as: Y (action taken), 0 (no action taken) and L (limited action). Limited action usually referred to addressing DFM objectives similar to their daily objectives, but not specifically with respect to EFJV. One exception was the municipality, which addressed objectives with respect to EFJV, but from a police perspective, not their own.

### *3.6.2 Activities in the context of Civil Protection*

For the purpose of placing farming actors' activities in context with the overall response, the activities of the local chief of police are discussed here and the broader aspect of Civil Protection. Disaster-related activities in Iceland are by law coordinated by chiefs of police at the local level and by the National Commissioner of the Icelandic Police at the national level, managed by a Civil Protection and Emergency Management Department (Act on Civil Protection, *Lög um almannavarnir* 2008). The national level also responds locally, for example, by running a temporary service centre, and providing guidance to residents regarding ash and other volcanic hazards through pamphlets and the Internet (www.almannavarnir.is).

Shortly after the 1999 earthquake swarms in EFJV, scientists notified the National Civil Defence of Iceland (now Civil Protection Department of the National Commissioner of the Icelandic Police since 2003) of these events, which initiated a discussion of a possible eruption. At the time, a significant amount of research had been published on eruptions of Katla, the neighbouring volcano and subsequent flooding, as it was seen as a risk due to past activity (see Fig. 6), but less on the EFJV.

The interview with the local chief of police revealed the following (see Tables 8 and 9). The local police do not perform natural disaster risk analyses, but they sent a letter of request to the Minister of Justice (now Interior) in 2002 to fund a scientific risk analysis for the Katla and Eyjafjallajökull volcanoes. The analysis was published in 2005 (Gudmundsson et al. 2005). It was a flood hazard analysis only; ash hazard was not included. A digitized simulation of floods on topographical maps was produced for the area; however, exposure, vulnerability or risk studies were never completed. The local police did not perform or coordinate any direct mitigation activities, but did encourage others to do so.

**Table 8** Actors' activities to achieve objectives

| No. | Actor | Activities to achieve objectives 1–3 Pre-disaster | Activities to achieve objectives 4–7 Disaster operations | Activities to achieve objective 8 Systematic learning |
|---|---|---|---|---|
| 1 | Ministry of Agriculture | Did not perform any pre-event activities | Financial issues and high-level coordination. Responsible for the recon mission | The process of monitoring the situation, discussing the situation at meetings and listening to presentations was a learning process, but no systematic learning has taken place within the ministry. The Secretary General of the Ministry of Agriculture had asked those legally responsible for disaster coordination (Minister of Interior and National Police Commissioner), at a meeting during the response, for clarification on the role of the Ministry of Agriculture, but did not receive any clarification and remains uncertain who is responsible for initiating a systematic learning process |
| 2 | Farmers' Association of Iceland | Did not perform any pre-event activities | Responsible for the recon mission. Monitored information about ash and chemicals, and supported the Farmers' Insurance Fund in collecting information about damages to fields, field roads, ditches, field fences, loss of harvest, evacuation of animals (transport and care-taking at a new location), livestock and livestock production | Dedicated a one-day session of their 2011 Annual Conference to presentations on EFJV and published the abstracts (Farmers' Association 2011), thus providing a venue for others, but had not performed any internal learning at the time of the interview |
| **3** | South-Agri: Agricultural Association of South Iceland | Did not perform any pre-event activities | Responsible for the recon mission. Lower-level coordination role, for example, on animal evacuation. Monitored information about ash and chemicals, and supported the Farmers' Insurance Fund in collecting information about damages to fields, field roads, ditches, field fences, loss of harvest, evacuation of animals (transport and care-taking at a new location), livestock and livestock production | Updated their website information and wrote an evaluation paper presented at the Annual Meeting (Sigurmundsson 2011) and have the view that the government officials should develop response plans covering livestock evacuation and support to farmers. Have not formally institutionalized lessons from the event |

**Table 8** continued

| No. | Actor | Activities to achieve objectives 1–3 Pre-disaster | Activities to achieve objectives 4–7 Disaster operations | Activities to achieve objective 8 Systematic learning |
|---|---|---|---|---|
| 4 | The Icelandic Food and Veterinary Authority | Worked on risk and mitigation from their daily perspective of food and animal health. Requested to be included in an emergency evacuation and communication exercise in 2006, but the request was denied due to relevance | Participated in developing an ad hoc coordination mechanism and focused on situation monitoring, assigned experienced vets (but untrained for surveying) to survey the area, monitored the conditions of the animals, discussed issues of emergency slaughtering of animals with slaughterhouse managers, issues of collecting milk and spoilt milk with the dairy | Are in the process of deciding how to address the issue of improving their procedures |
| 5 | The Agricultural University of Iceland | Teaches students about the risk to animals from fluoride | Participated in measuring chemicals on the farmlands | Do not plan to systematically learn from this event |
| 6 | Land Conservation Authority | Battles land erosion due to wind and floods, e.g., builds flood barriers and cultivates land, and worked towards stabilizing ash with a focus on Hekla and Katla Volcanoes | Did not have a direct role, but offered resources, such as, land for temporary grazing, fencing, machinery and housing for families. Witnessed during the eruption how cultivating land next to roads improved road safety increases driver's road visibility | Developed ideas for changed working procedures and incorporated some of them |
| 7 | Farmers' Insurance Fund | Procedures were available prior to the 2010 eruption for the staff to follow in case of a natural disaster, but the procedures were not specific to EFJV | Developed payment rules for the EFJV event (Farmers' Insurance Fund Rules 2010) after the extent of damage was known. Played a relief role by paying out insurance prior to final investigation of damages, when the damage was obvious | Believe their procedures work well and require no revision |
| 8 | Iceland Catastrophe Insurance | Procedures were available prior to the 2010 eruption for the staff to follow in case of a natural disaster, but the procedures were not specific to EFJV | Financial role. Was prepared to pay for measures to stop on-going damage, if needed | Implemented improved procedures |

**Table 8** continued

| No. | Actor | Activities to achieve objectives 1–3 Pre-disaster | Activities to achieve objectives 4–7 Disaster operations | Activities to achieve objective 8 Systematic learning |
|---|---|---|---|---|
| 9 | Directorate of Labour | Did not perform any pre-event activities | DoL's involvement was coincidental. In 2010 unemployment was still high due to the banking collapse in 2008. Some of the DoL beneficiaries still work for the LCA | Saw the event as an unusual occurrence and therefore no need to change procedures |
| 10 | Chief of Police | Requested the Minister of Justice to fund a scientific risk analysis of Eyjafjallajökull and Katla Volcanoes. Only a flood hazard analysis was performed. Did not mitigate risk, but encouraged others to do so. Used hazard analysis to plan evacuation | Monitored information about the natural processes, evacuated people and ensured people's safe return to their homes. Have a coordination role from the perspective of civil protection | In the process of systematically implementing lessons from the event, doing so from a police and civil protection perspective |
| 11 | Municipality of Rangarthing Eystra | Participated in river flood barrier planning, based on a risk analysis done by others, e.g., Land Conservation. They participated in police planning, but did not plan for problems within municipal services | Participated in activities led by the police. Tended to their own services by covering road drains to prevent them for being clogged by ash and assisting farmers in restoring local electricity and obtaining financial aid from the government | Have not participated in any type of learning activities |

The 2005 hazard analysis was used to update existing evacuation plans for Katla to include EFJV. The police/Civil Protection coordinated a full-scale evacuation and communication exercise in 2006 for emergency services and citizens (Department of Civil Protection and Emergency Management 2006). In the weeks prior to the eruption, the local chief of police held approximately 10 town hall meetings, including one with presentations from scientists, rescue teams and the National Commissioner of the Icelandic Police. The main focus of learning from the police perspective after the event has been on improving technical communications.

In the early morning of 14 April, some 800 residents were evacuated due to the summit eruption. Most of them were allowed to go back the same day and the rest the day after (Gudmundsson et al. 2010) for safety reasons, depending on how close they lived to the rivers that were in danger of flooding. After the evacuation, the farmers wanted to go back to their farms to tend to their animals. The police allowed temporary visits during the evacuation period after a mobile phone-monitoring system had been set up to call farmers out of the area if need be.

A temporary service centre was set up in the lowland farming area at the south-western corner of EFJV (Heimaland), where those affected could talk to representatives of various

**Table 9** Actors' activities to achieve objectives coded

| Actor | Disaster-function management objectives | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1. Ministry of Agriculture | 0 | 0 | 0 | Y | Y | Y | Y | 0 |
| 2. Farmers' Association of Iceland | 0 | 0 | 0 | Y | Y | Y | Y | 0 |
| 3. South-Agri: Agricultural Association of South Iceland | 0 | 0 | 0 | Y | Y | Y | Y | L |
| 4. The Icelandic Food and Veterinary Authority | L | L | L | Y | 0 | Y | 0 | L |
| 5. The Agricultural University of Iceland | L | 0 | 0 | Y | 0 | 0 | 0 | 0 |
| 6. Land Conservation Authority | L | L | L | Y | 0 | Y | Y | Y |
| 7. Farmers' Insurance Fund | 0 | L | L | 0 | 0 | Y | Y | 0 |
| 8. National Catastrophe Insurance Fund | L | L | L | Y | 0 | Y | Y | Y |
| 9. Directorate of Labour | 0 | 0 | 0 | 0 | 0 | Y | 0 | 0 |
| 10. Chief of Police | Y | 0 | Y | Y | Y | 0 | 0 | Y |
| 11. Municipality of Rangarthing Eystra | 0 | L | L | Y | Y | Y | Y | 0 |

Y (Yes), action to achieve objective regarding EFJV

0 (Zero), no action to achieve objective regarding EFJV

L (Limited), some action taken related to achieving the objective regarding volcanic eruptions, but not directly aimed at EFJV

services, such as insurance companies, building authorities, medical and farmers' extension services (Thorkelsson 2012). The manager was a policeman and represented the National Commissioner of the Icelandic Police. His role was to provide advice and information to the affected population (citizens and municipal staff), coordinate projects with the municipalities in recovery and liaise with ministries and agencies, for projects related to the eruption (Department of Civil Protection and Emergency Management 2010). The manager also had considerable knowledge of agriculture, which motivated The Farmer's Association to work with him (Bjarnason 2014). A staff member of the National Police Commissioner also visited farms during the eruption to give general advice to farmers.

### 3.7 Farmers' livelihood outcome in 2010

The farming livelihood outcome for 2010 is described, based on the evaluation of farmers' situation by the recon team (see Table 10). The organizers identified various unanswered questions, issues of concern and priority actions relating to chemical analysis and monitoring, animal sheds, hay and fodder, labour support, rest periods for farmers, animal transport, pastures, soil, crops and the use of fertilizer for farmland rehabilitation. Damage to buildings was not an issue because the Iceland Catastrophe Insurance insured building damage, and fire departments, rescue teams and volunteers, organized by non-farming actors, provided services to wash buildings.

## 4 Analysis

The farming-EFJV perspective (presented in Sect. 3) was used as a basis to answer a question relevant to each disaster-related objective (in *italics* below). The answers are

Table 10 Recon teams' viewpoint after field visits

| Category | Issue |
|---|---|
| Questions needing answers | Where is it safe for the sheep to be in regards to ash? Are the highlands safe? Where should the sheep that normally graze in the summer, roaming free in the highlands, be sent? |
| | Should transport be the responsibility of each farmer, or should it be a collective effort? |
| | Where are farmers allowed to move their sheep in regards to disease control zones? |
| | Who will pay for fencing for temporary pasture areas and fertilizing? |
| Issues of concern | The fluoride sampling, analysis and reporting are taking too long as analysts are not working on weekends |
| | Need to discuss in earnest how to help farmers wanting to stop farming and permanently relocate, which requires financial support |
| | The working procedures adopted by the Farmers' Insurance Fund for the eruption were not yet clear |
| | Information to farmers needs to be more appropriate; both the content and method of the Internet are not enough, nor is general information |
| | The actors involved in decision-making processes need to be more decisive |
| Priority action areas/ responsible actor(s) | Temporary pasture/South-Agri |
| | Sheds/South-Agri |
| | Hay and fodder/Municipality, Farmers' Association and South-Agri |
| | Labour support/Farmers' Association and South-Agri |
| | Rest periods for farmers/Ministry of Agriculture |
| | Animal transport/Farmers' Association and South-Agri |
| | Soil, crops and use of fertilizer for rehabilitation of farm land/Recon teams were not sure which actors were responsible for this issue |
| | Chemical analyses and monitoring/Agricultural University, Farmers' Association and South-Agri |

presented in bullet form for each objective and summarized in Table 11 as missing or unplanned activities.

For the sake of brevity, only the activities of the direct farming actors (first seven in Table 7) are included, and the activities for all four operational objectives (4, 5, 6 and 7) are viewed together.

## 4.1 Risk analysis activities (Table 2, Obj. 1)

*Would it have been possible to perform a useful risk analysis from a farming perspective prior to the eruption?* A risk analysis is based on exposure, hazard and vulnerability analyses. The area exposed to an eruption in EFJV is a small farming community. Information about farming livelihood strategies was available, and numerous actors were involved in the farming processes (Sect. 3.1). Therefore, detailed information about exposure in terms of assets and processes could have easily been collected. Hazard research prior to the eruption indicated that Iceland is an active volcanic island, that an explosive and/or effusive eruption, a summit and/or flank eruption, intermittent eruption, harmful ash levels, lightning, $CO_2$, lava flow, tephra fall, fluorine, sand and dust from volcanic ash, floods with ice melt and waterborne ash could have been expected from an eruption in

**Table 11** Missing or unplanned activities per objective

| No. | Function | Activities |
|---|---|---|
| 1 | Risk Analysis | Information was available on the volcanic hazard in Iceland, particularly on Eyjafjallajökull, on the exposed area, on the vulnerability of farming due to ash and on general livelihood strategy variables. A useful risk analysis to inform mitigation and preparedness from a farming perspective could have been developed |
| 2 | Mitigation | Efforts to control ash, sand and dust from volcanoes in Iceland systematically applied in various regions in Iceland could have been systematically applied to the EFJV area to reduce the risk of negative affects of ash distribution |
| 3 | Preparedness | Some discussions during the response, such as which actor would monitor chemical levels, which actor would pay for it, whether to perform a recon, etc., could have been a preparedness activity and resulted in coordination plans. Training in disaster assessment and coordination could have inspired farming actors to perform recon missions soon after the onset and periodically, to develop specialized farming information management procedures and might have increased operational decisiveness |
| 4–7 | Operations (impact, rescue, relief and recovery) | Due to necessity and regardless of any preparation, farming actors will organize their own coordination mechanism, based on their daily modes of communication, to deal with activities for damaging processes, rescue, relief and recovery from their perspective, and link it to other operational coordination mechanisms |
| 8 | Systematic learning | In 2013, no systematic learning had taken place amongst the farming actors since the eruption in 2010. It is unclear who should take the initiative for starting a learning process |

Iceland, and that Eyjafjallajökull was an active volcano (Table 4). Ash levels from EFJV had not been estimated in the hazard analysis of EFV in 2005, but a 20-cm ash cover (Fig. 6) was expected in the exposed area, given eruptions in other nearby volcanoes. Degassing of magma and subsequent chemical transfer into the atmosphere, onto the ground and into rivers, were known threats. When EFJV erupted in 2010, it did indeed involve effusive and explosive eruptions, flank and summit eruptions, magma discharge of lava flow, water-transported ash and airborne ash, plume, ice melt, glacial river flooding and lightning, and the ash level in the farming areas was measured well below the 20 cm mark (Fig. 7). Therefore, the EFJV 2010 was well within the range and type of an expected volcanic eruption in the region. In regard to vulnerability, research had presented numerous possible effects on natural and physical assets (Table 5). A comparison of Tables 5 and 6 shows that various issues for farmers, such as ash covering pastures, fodder, water, visibility, animal fluoride tolerance, soil conditions and general interruption of agricultural activities (Table 6), had been discussed in previous research (Table 5). Farming in Iceland has changed significantly through the centuries, for example, through technical advances in harvesting and milking, increased societal knowledge and increased education amongst farmers (Jóhannesson and Agnarsson 2005). Changes in production lead to changes in vulnerability; for example, increased technology may decrease (e.g., produce fodder faster) or increase disaster vulnerability (e.g., damage to machinery), calling for periodically updated disaster risk analysis from a farming perspective.

- Yes. The actual impact from Eyjafjallajökull was within the range of a hazard analysis from a volcanic eruption in the region, so a risk analysis would have been useful.

### 4.2 Disaster Risk Mitigation activities (Table 2, Obj. 2)

*Could a mitigation analysis prior to the eruption have led to ideas on how to reduce disaster risk?* A sound risk analysis would have informed a detailed mitigation analysis and led to realistic ideas for mitigating measures taken by farmers, their families and farming actors in regard to damage, injury and disruption. One example is given here on increased visibility and traffic safety during ash storms. The Land Conservation Authorities systematically cultivates vegetation along roads to limit ash, sand and dust remobilization (e.g., in the Hekla region and the sands along the south coast) to increase visibility whilst driving in sandstorms and reduce the risk of scratching car paint (see daily objectives in Table 7). A stretch along the main road in the EFJV area had been cultivated by Land Conservation prior to the eruption for these reasons, which were reasons unrelated to the risk of an eruption in EFJV. During ash storms from the eruption, Land Conservation staff members saw that ash density blowing over the roads along the cultivated land was less than in other places, facilitating traffic and increasing road safety because it was easier to see the road. If the agency had been aware of the risk, they could have put efforts into cultivating more land next to the main road in the EFJV region to reduce ash mobilization over main roads.

- Yes. A systematic mitigation analysis could have led to increased visibility and road safety during ash storms and knowledge of vulnerability processes would have been the basis for further analysis.

### 4.3 Operational Preparedness activities (Table 2, Obj. 3)

*Could a useful contingency plan have been written by and for the farming community to guide impact, rescue, relief and/or recovery operations?* When prompted by a realistic risk scenario, farming actors, with their knowledge of farming processes, such as lambing, sheltering of animals, the need for feed, etc., would likely have been able to identify content for a contingency plan to guide the response of the farming actors. Examples include: identifying responsible parties for paying for fencing and fertilizing, for temporary pastures, for the transport of animals and for people organizing chemical analysis and reporting; developing standard operating procedures to ensure that information to farmers is appropriate in content, format, timing and delivery; and that farmers are provided with rest periods. The actors may have identified the need for further research on animals' fluoride tolerance, health effects, the effect of ash on soil and vegetation of fields and pastures, on factors to consider in deciding whether to build additional shelter for animals or to evacuate them, and, if they are evacuated, who will tend to them in the new location—for example, milking cows. Preparing a contingency plan could have led farming actors towards training in establishing coordination mechanisms and needs assessment.

- Yes, useful contingency plans could have been written by and for the farming community prior to the eruption, if based on a sound risk scenario and accompanied by training in disaster operations.

### 4.4 Operational activities (Table 2, Obj. 4, 5, 6 and 7)

*Could coordination and assessment efforts amongst farming actors have been performed better?* Impact, rescue, relief and recovery operations require effective coordination and timely needs assessments. Establishing such processes at the onset of a disaster is a standard operating procedure (UNOCHA 2006). Coordination was initiated by the national government when it formed a committee of the secretaries general of the ministries the day after the eruption. Subsequently, the Secretary General of the Ministry of Agriculture formed a coordination group of farming actors that included the Farmers' Association. The Farmers' Association coordinated with South-Agri. The South-Agri offices, situated in the town of Selfoss between the capital, Reykjavik, and the affected area (See Fig. 4), became the centre of coordination for field activities. South-Agri field staff in the affected area also reacted to the situation by helping farmers move animals into shelters. Thus, the farming community created its own disaster coordination mechanism under the Ministry of Agriculture, based on their normal collaborative network. This mechanism was linked to the coordination mechanism of the police/Civil Protection, for example, through cooperation between the Ministry of Agriculture and South-Agri with the manager of the Temporary Service Centre. The Food and Veterinary Authorities also participated in developing an ad hoc coordination mechanism with various other actors. The initial reaction to the eruption was more or less immediate (according to interviews) and mainly in accordance with their daily objectives (see Table 7). However, in regard to assessments, despite a general understanding of the situation, a joint needs assessment was not performed until four weeks into the operation when the situation in the field had become problematic and farming actors were beginning to show fatigue. The eventual needs assessment systematically and collectively gathered and analysed information to allocate resources and assist the affected farming and animal populations and agricultural facilities in a concerted effort.

- Yes. Whilst initial efforts were immediate, the coordination for farming actors was ad hoc, and a systematic needs assessment was performed four weeks into the event, prompted by awareness of the problematic situation. This is reactive management. Proactive management could have led to a better performance, e.g., an earlier recon mission.

### 4.5 Systematic learning activities (Table 2, Obj. 8)

*Would systematic learning from farming actor activities associated with the 2010 eruption be useful?* Lack of farming-disaster risk analysis (4.1), systematic mitigation analysis (4.2) and disaster training and planning (4.3) led to ad hoc, reactive and delayed measures (4.4). These facts provide reasons for farming actors to separately and jointly review their pre-eruption and real-time EFJV-related activities to learn lessons in case of future and possibly larger eruptions. Lack of pre-disaster planning leads to more time spent on operational planning after the onset of the disaster, causing delays in assistance reaching the affected population. Indeed, the lack of plans resulted in discussions amongst farming actors on what to do, on clarifying actors' responsibilities, such as determining responsibility for organizing field sampling and reporting schemes for chemical monitoring, determining logistical support for animal evacuation, estimating operational cost and deciding who shall pay for what, determining coordination mechanisms and resolving other issues normally addressed in contingency plans to ensure effective and efficient response operations, taking place *after* the eruption started. Learning processes should also address gaining clarity on the roles and responsibilities of ministries before, during and after disasters. The Ministry of Agriculture sought clarification on their role from those legally responsible for disaster coordination, i.e., the Minister of the Interior and National Commissioner of the Icelandic Police, but no clarification was received. At the time of the interview, it was still unclear who bore the responsibility for initiating a systematic learning process.

- Yes. A systematic learning process could reveal the current knowledge of farming actors in regards to risk analysis, mitigation and preparedness, could increase pre-planning to shorten operational planning and hasten field response and could clarify roles and responsibilities in the farming community.

## 5 Results

The reason for inadequate information getting to farmers during the 2010 includes lack of pre-eruption activities by farming actors regarding an eruption in EFJV. Four of the seven farming actors performed no risk analysis at all, whilst three performed general activities related to ash risks. Five farming actors took no mitigation measures, and two participated in mitigation-related activities for general volcanic threats. No farming actor initiated any activity towards designing a coordination mechanism or writing a contingency plan for farming actors as a group. Risk analysis, mitigation analysis and contingency planning could have prepared the actors to collect, compile and timely share relevant information.

Inadequate information for farmers can also be linked to the delay in joint needs assessment. The reason for the delay can be attributed to lack of training in disaster management, leaving farming actors to gradually realize problems amongst farmers as the problems grew bigger and therefore manage reactively.

The lack of pre-event activities is not due to insufficient pre-eruption information. On the contrary, substantial information was available to perform a realistic risk analysis for EFJV from a farming perspective. The hazard was well known, the exposure area was small with well-understood assets and processes, and relevant vulnerability studies existed that could have been used as a basis of further vulnerability analysis. The resulting risk scenario would have resulted in a higher intensity scenario than actually occurred; therefore, any planning for the risk scenario would have been within the scope of the actual event.

The study shows a lack of post-event learning. Four farming actors had not initiated a process to learn from their experiences (one actor believed its institute did not need to do so). Two have initiated, but not completed, a learning process. One has changed response procedures, based on the experience, but none has initiated a learning process for the farming community in general. The experience did give some actors insight into what could have been improved. For example, during an interview one actor stated that, in retrospect, the recon should have been performed sooner and more often, but this has not been enough to initiate a learning process within the learning community.

## 6 Discussion on perspective

The impact of the EFJV eruption was not a disaster by the UN's definition of disaster (UNISDR 2009), as it did not cause disruption at the community level to the extent that it exceeded society's ability to function. The serious disruption was on the farm level. There were less than 20 farms in the main affected areas, and fewer than 10 of these were in the most affected area (see Fig. 4a). There was general agreement amongst the interviewees that the coping level of actors and farmers was due to fortunate circumstances: a small, homogeneous, sparsely populated affected area, where the farmers and institutional farming staff knew each other very well, and unfavourable winds were of short duration. Nevertheless, numerous groups were involved, demonstrating the diversity of perspective in the disaster-related activities. For example, scientists, police and farming actors have different roles and responsibilities and demonstrated different perspectives on what constitutes disaster-related activities.

Scientists had monitored the EFJV volcano since 1991, reported the activity to the Civil Protection after it increased in 1999, presented a detailed analysis of flood-related hazards due to EFJV and Katla Volcano in 2005, where ash was not considered, published a hazard assessment in 2008 of a 20 cm ashfall around EFJV and increased their monitoring of EFJV as the activity increased in the months prior to the eruption. A scientific field assessment includes a detailed assessment of ashfall, e.g., analysing the thickness of ash versus the intensity or degree of impact, the frequency, duration and magnitude of the ashfall event, along with the characteristics of ash, such as grain size, mineralogy and content of soluble acidic salts associated with the ash (Wilson et al. 2011a, b). The results of such activities include information like that presented in Fig. 7. No risk analysis was performed, other than mapping of a flood zone and locating constructed elements in the flood zone.

The police, after being informed of the hazard by the scientific community, initiated funding for further hazard analysis relevant to life safety from flooding due to eruption under icecaps, and organized evacuation exercises in the event of flooding. Icelandic law makes pre- and real-time disaster coordination the responsibility of the police. They were actively engaged in coordinating various actors, mainly emergency management agencies, for eight years prior to the eruption. They focused on life-saving activities. In March 2013, three years after the eruption, the local and national police and the local Civil Protection Committee published the first formal response plan specifically for an eruption in the EFJV (Police Chief Hvolsvelli et al. 2013). Its content focuses on population control, evacuation, mass care, traffic control, rescue and flood control. The only farming actor is the National Veterinarian, who works within the Food and Veterinarian authorities. His role during an eruption, according to the plan, is to "work according to his own plan". The new plan clearly shows that the police perspective does not include the perspective of farming actors.

Despite a history of volcanic impact on farms in Iceland, the farming actors were not informed of the increasing risk. They did not initiate any type of pre-disaster activities and have not (at the time of the interviews) engaged in systematic learning as a community. The farming actors are not considered part of the Civil Protection umbrella since they were not invited to participate in preparedness activities with emergency agencies and are not part of the latest police response plan. However, farming actors were highly active during the response and are important response actors for farmers. The Ministry of Agriculture, the Farmers' Association and South-Agri participated to some degree in activities regarding all four operational objectives, where the life-saving objective (Objective 5 in Table 2) relates here to the lives of the livestock. Failure to identify relevant stakeholders (actors and those affected) has been documented as one of the possible reasons for systems failure (Lyytinen 1988, Pouloudi and Whitely 1996). The question becomes who is responsible for identifying and activating stakeholders to avoid systems failure.

The point argued here is that the level of specialization amongst livelihood professionals in general requires them do their own risk and mitigation analyses and to prepare their own disaster-related activities and coordination mechanisms. The consequences of ashfall on farming are not well understood by non-specialists. Brunsdon and Park (2009) reach a similar conclusion from the perspective of designing and managing infrastructure when they suggest that consequences to a community due to infrastructure failure are not well appreciated by other utility providers, civil defence agencies, businesses and communities.

## 7 Conclusions

The reason for inadequate information to farmers can be attributed to lack of pre-eruption activities amongst farming actors, stemming from lack of clarity on who bears the responsibility for identifying actors to assist farmers from a livelihood perspective and initiating their pre-disaster activities.

Livelihood actors provide specialized knowledge on their specific fields and in times of disaster can offer specialized solutions for their industry that are beyond the perspective of emergency services. However, being highly specialized in their field is not enough when it comes to responding effectively and efficiently to disasters. First, specialists need to be updated on any developments regarding natural hazards. Second, they need to be trained in disaster-related activities and standard operating procedures, such as developing disaster risk scenarios from a livelihood perspective, building coordination mechanisms, initiating timely needs assessment and sharing specialized information. The failure to identify farming actors prior to 2010 resulted in lost opportunities to analyse farming-disaster risk and mitigation options, organize coordination mechanisms for farmers and write contingency plans. Livelihood actors should take the initiative in analysing disaster-related legal frameworks from their own perspective to identify and address gaps, such as the provision of information important in their field.

This study provides numerous ideas for further research. For example, additional questions can be asked on the information in Sect. 3. For instance, how to develop a risk-planning scenario from a farming perspective, and what recon questions provide the most useful information. However, the main topic of future research is seeking clarity on the roles within legal frameworks for disaster-related activities, in order to determine necessary changes to such frameworks, to ensure effective and efficient pre-event, real-time and post-event activities amongst livelihood actors.

**Acknowledgments** Sincere gratitude is expressed for the time and invaluable contributions of the staff members at the 11 institutions interviewed for this study. Runólfur Sigursveinsson at South-Agri is especially thanked for his role in providing information for this study. Eiríkur Blöndal, managing director of the Farmers' Association, is thanked for his eloquent summarization of the key lesson drawn from the EFJV for the farming industry in Iceland. Sigurgeir Thorgeirsson, former Secretary General of the Ministry of Agriculture, is thanked for his review comments. Puja Acharya is thanked for her assistance in generating the maps and her patience. Dr. Magnús Tumi Gudmundsson is thanked for permission to use Fig. 6. We also thank the anonymous reviewers for constructive comments and their guidance in restructuring the paper. The authors gratefully acknowledge the research grants from the University of Iceland's Eimskip Fund and the South Iceland Science Fund. Furthermore, the co-support provided by the EU Civil Protection Financial Instrument, in the framework of the European project Urban disaster Prevention Strategies using MAcroseismic Fields and FAult Sources (Acronym: UPStrat-MAFA, Grant Agreement No. 23031/2011/613486/SUB/A5), is gratefully acknowledged.

## References


Alexander D (2006) Globalization of disaster: trends, problems and dilemmas. J Int Aff 59(2):1–22

Annen C, Wagner J-J (2003) The impact of volcanic eruption during the 1990s. Nat Hazards Rev 4:169–175

Arnalds O (2010) Dust sources and deposition of Aeolian materials in Iceland. Icel Agric Sci 23:3–21

Arnalds O, Gisladottir FO, Sigurjonsson H (2001) Sandy deserts of Iceland: an overview. J Arid Environ 47:359–371

Arnalds O, Thorarinsdottir AF, Thorsson J, Waldhauserova PD, Agustsdottir AM (2013) An extreme wind erosion event of the fresh Eyjafjallajökull 2010 volcanic ash. Sci Rep 3:1257

Bændabladid (2014) Ályktanir Búnaðarþing 2014. 6 March 2014

Bird DK, Gisladottir G (2012) Residentś attitudes and behaviour before and after the 2010 Eyjafjallajökull eruptions—a case study from southern Iceland. Bull Volcanol 74:1263–1279

Bird DK, Gisladottir G, Dominey-Howes D (2010) Volcanic risk and tourism in southern Iceland: Implications for hazard, risk and emergency response education and training. J Volcanol Geoth Res 189:33–48

Bjarnason T (2014) PR and Publications officer, Farmers' Association of Iceland, email communication

Brunsdon D, Park B (2009) Lifeline vulnerability to volcanic eruption: learnings from a national simulation exercise. TCLEE: Lifeline Earthquake Engineering in a Multihazard Environment, ASCE, USA

Cannon T, Twigg J, Rowell J (2005) Social vulnerability, sustainable livelihoods and disasters. Report to Department for International Development, UK

Cronin SJ, Hedley MJ, Neall VE, Smith RG (1998) Agronomic impact of tephra fallout from the 1995 and 1996 Ruapehu Volcanic eruptions, New Zealand. Environ Geol 34(1):21–30

Department of Civil Protection and Emergency Management (2006) Skýrsla Bergrisinn 2006, National Commissioner of Icelandic Police

Department of Civil Protection and Emergency Management (2010) Samantekt um stöðu verkefna og tillögur um aðgerðir vegan eldgosa á Fimmvörðuhálsi of í Eyjafjallajökli vorið 2010, National Commissioner of Icelandic Police

DFID, Department for International Development (1999) Sustainable Livelihoods Framework Guidelines. http://www.ennonline.net/resources/667, extracted June 2, 2013

Dugmore AJ, Newton AJ, Smith KT, Mairs K-A (2013) Tephrochronology and the ate Holocene volcanic and flood history of Eyjafjallajökull, Iceland. J Quat Sci 28(3):237–247

Eyvindsson, E (2013) farmer, personal communication

Farmers' Association (2011) Fræðaþing landbúnaðarins, Málstofa A, Eldgosið í Eyjafjallajökli; - áhrif þess á samfélag, búskap, dýralíf og gróður. Conference proceedings, Iceland

Farmers' Insurance Fund Rules (2010) Reglur um aðstoð Bjargráðasjóðs vegan tjóns af völdum öskufalls og flóða vegan eldgosa, Farmerś Insurance Fund, Iceland

Farmers' Reconnaissance Report (2010), Skýrsla Bændasamtaka Íslands um ástand á áhrifasvæðum eldgossins í Eyjafjallajökli Maí 2010, Iceland, Farmer' Association of Iceland

Ghuman K (2010) Management: concepts, practice and cases. Tata McGraw Hill, New Delhi

Gislason SR (2000) Koltvíoxíð ($CO_2$) frá Eyjafjallajökli, February Meeting 2000 proceedings, Geoscience Society of Iceland, 20–21

Gislason J (2013) brautarstjóri búfræðibrautar, teacher, Agricultural University of Iceland, personal communication

Gislason SR, Alfredsson HA (2010) Sampling the volcanic ash from the Eyjafjallajökull volcano, Iceland - A personal account. Elements 269–270

Gislason SR, Hassenkam T, Nedel S, Bovet S, Eiriksdottir ES, Alfredsson HA, Hem CP, Balogh ZI, Dideriksen K, Oskarsson N, Sigfusson B, Larsen G, Stipp SLS (2011) Characterization of Eyjafjallajökull volcanic ash particles and a protocol for rapid risk assessment. PNAS 108(18):7307–7312

Gudmundsson MT (2014) Professor at the University of Iceland, personal communication

Gudmundsson A, Oskarsson N, Gronvold K, Saemundsson K, Sigurdsson O, Stefansson R, Gislason SR, Einarsson P, Brandsdottir B, Larsen G, Johannesson H, Thordarson T (1992) The 1991 eruption of Hekla, Iceland. Bull Volcanol 54:238–246

Gudmundsson MT, Elíasson J, Larsen G, Gylfason Á G, Einarsson P, Jóhannesson T, Hákonardóttir KM, Torfason H (2005) Yfirlit yfir hættu vegna eldgosa og hlaupa frá vesturhluta Mýrdalsjökuls og Eyjafjallajökli (Overview of hazard due to eruptions and jökulhlaups from the western part of Mýrdalsjökull and Eyjafjallajökull). In: Gudmundsson MT and Á. G. Gylfason eds. *Hættumat vegna eldgosa og hlaupa frá vestanverðum Mýrdalsjökli og Eyjafjallajökli,* Ríkislögreglustjórinn og Háskólaútgáfan, 11–44, Iceland

Gudmundsson MT, Larsen G, Hoskuldsson A, Gylfason AG (2008) Volcanic hazards in Iceland. Jökull 58:251–268

Gudmundsson MT, Pedersen R, Vogfjord K, Thorbjarnardottir B, Jakobsdottir S, Roberts MJ (2010) Eruptions of Eyjafjallajökull Volcano, Iceland. EOS 91(21):190–191
Gudmundsson MT, Thordarson T, Hoskuldsson A, Larsen G, Bjornsson H, Prata FJ, Oddsson B, Magnusson E, Hognadottir T, Petersen GN, Hayward CL, Steveson JA, Jonsdottir I (2012) Ash generation and distribution from the April–May 2010 eruption in Eyjafjallajökull, Iceland. Sci Rep 2:572
Hjaltadottir S, Vogfjord K (2010) Seismic evidence of magma transport in Eyjafjallajokull during 2009–2010. Eos 91(Fall meet. suppl) (abstract V21F-02)
Iannella R, Henricksen K (2007) Managing information in the disaster coordination centre: lessons and opportunities. In: Proceedings of the 4th international ISCRAM conference, Delft, The Netherlands
Jóhannesson S, Agnarson A (2005) Bóndi er bústólpi, bú er landstólpi. Annual Report 2004, Institute for Economic Studies, University of Iceland
Kelman I, Mather TA (2008) Living with volcanoes: The sustainable livelihoods approach for volcano-related opportunities. J Volcanol Geoth Res 172:189–198
Kristinnsson J, Gunnarsson E, Jóhannesson Th, Pálsson PA, Thormar H (1997) Experimental fluoride poisoning in Icelandic sheep. Icel Agr Sci 11:107–112
Larsen G (1999) Gosið í Eyjafjallajökli 1821-23. RH-28-99, Sci. Inst., Univ. of Iceland, Reykjavík
Larsen G (2013) Volcanologist at the University of Iceland, personal communication
Lebon SLG (2009) Volcanic activity and environment: Impacts on agriculture and use of geological data to improve recovery processes. Masters Thesis in Environmental Sciences and Natural Resources Management, Earth Science Institute, University of Iceland, Reykjavik, ISBN 978-9979-9914-0-3
Lög um almannavarnir (2008) nr. 82 12. juni. http://www.althingi.is/lagas/139b/2008082.html. Extracted June 2013
Lyytinen K (1988) Stakeholders, IS failures and soft systems methodology: an assessment. J Appl Syst Anal 15:61–81
Magill C, Wilson T, Okada T (2013) Observations of tephra fall impacts from the 2011 Shinmoedake eruption, Japan. Earth Planets Space 65:677–698
McEntire DA, Fuller C, Johnston CW, Weber R (2002) A comparison of disaster paradigms: the search for a holistic policy guide. Publ Adm Rev 62(3):267–281
National Governors' Association (NGA) (1979) Comprehensive Emergency Management: A Governor's Guide. National Governors' Association, Center for Policy Research, Washington
Neal DM (1997) Reconsidering the phases of disaster. Int J Mass Emerg Disasters 15(2):239–264
Odero K (2006) Information Capital: 6th asset of sustainable Livelihood Framework. Discov Innov 18(2):83–91
Oskarsson N (1980) The interaction between volcanic gases and tephra: fluorine adherig to tephra of the 1970 Hekla eruption. J Volcanol Geoth Res 8(2–4):251–266
Pedersen R, Sigmundsson F (2004) InSAR based sill model links spatially offset areas of deformation and seismicity for the 1994 unrest episode at Eyjafjallajökull volcano, Iceland. Geophys Res Lett 31:L14610
Pedersen R, Sigmundsson F (2006) Temporal development of the 1999 intrusive episode in the Eyjafjallajökull volcano, Iceland, driven from InSAR images. Bull Volcanol 68:377–393
Police Chief Hvolsvelli, Civil Protection Committee of Rangárvalla- and V-Skaftafellscounty and National Police Commissioner (2013) Viðbragðsáætlun vegan eldgoss undir Eyjafjallajökli. http://www.almannavarnir.is/upload/files/eldgos_Eyjafjallaj%C3%B6kull_%C3%BAtg%C3%A1fa_1_0_14032013.pdf, extracted November 2014
Pouloudi A, Whitely EA (1996) Stakeholder analysis as a longitudinal approach to interorganizational systems analysis. In: Proceedings of the 4th European conference on information systems, Portugal
Quarentelli EL (1996) Ten criteria for evaluating the management of community disasters. Preliminary paper #241, University of Delaware Disaster Research Center, USA
Scasso RA, Corbella H, Tiberi P (1994) Sedimentological analysis of tephra from the 12–15 August 1991 of Hudson volcano. Bull Volcanol 56:121–132
Sigmundsson F, Hreinsdottir S, Hooper A, Arnadottir T, Pedersen R, Roberts M, Oskarsson N, Auriace A, Decriem J, Einarsson P, Geirsson H, Hensch M, Ófeigsson BG, Sturkell E, Sveinbjornsson H, Feigl KL (2010) Intrusion triggering of the 2010 Eyjafjallajökull explosive eruption. Nature 468:426–431
Sigurmundsson S (2011) Aðstoð Búnaðarsamband Suðurlands við búfjárflutninga og tjónamat vegna eldgossins í Eyjafjallajökli. in Farmer' Association of Iceland (2011) Fræðaþing landbúnaðarins, Málstofa A, Eldgosið í Eyjafjallajökli; - áhrif þess á samfélag, búskap, dýralíf og gróður. Conference proceedings, Iceland
Spence RJS, Pomonis A, Baxter PJ, Coburn AW, White M, Dayrit, M, Field Epidemiology Training Program Team (1999) Building damage caused by the mount Pinatubo eruption of June 15, 1991. http://pubs.usgs.gov/pinatubo/spence/, extracted October 18th 2013

Spence RJS, Zuccaro G, Petrazzuoli S, Baxter PJ (2004) Resistance of buildings to pyroclastic flows: analytical and experimental studies and their application to vesuvius. Nat Hazards Rev 5:48–59
Sturkell E, Sigmundsson F, Einarsson P (2003) Recent unrest and magma movements at Eyjafjallajökull and Katla volcanoes, Iceland. J Geophys Res 108(B8):2368
Thordarson T, Hoskuldsson A (2008) Postglacial volcanism in Iceland. Jokull 58:197–228
Thordarson T, Larsen G (2006) Volcanism in Iceland in historical time: volcano types, eruption styles and eruptive history. J Geodyn 43:118–152
Thordarson Th, Self S, Oskarsson N, Hulsebosch T (1996) Sulfur, chlorine and flurorine degassing and atmospheric loading by the 1783–1784 AD Laki (Skaftár Fires) eruption in Iceland. Bull Volcanol 58:205–225
Thorkelsson K (2013) local chief of police, Rangarvallasysla, personal communication
Thorkelsson B, ed (2012) The 2010 Eyjafjallajökull eruption, Iceland. Report to ICAO, June 2012, Iceland, ISBN 978-9979-9975-4-2
Thorvaldsdóttir S, Sigbjörnsson R (2014) Disaster-function management: basic principles. Nat Hazards Rev 5(1):48–57
Twigg J (2004) Disaster risk reduction: mitigation and preparedness in development and emergency programming. Good Practice Review 9. Humanitarian Practice Network, Overseas Development Institute, London
UNISDR, United National International Secretariat for Disaster Reduction (2009) Terminology on disaster risk reduction, http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf, (extracted August 2012)
UNOCHA, United Nations Office for the Coordination of Humanitarian Affairs (2006) United nations disaster and coordination handbook https://docs.unocha.org/sites/dms/Documents/UNDAC%20Handbook-dec2006.pdf, extracted October 2013
Vetter D (1983) Ísland. Ferðasaga frá 17. öld, Sögufélag, Reykjavík, Iceland
Vogfjörd KS, Jakobsdottir SS, Gudmundsson GB, Robert MJ, Agustsson K, Arason T, Geirsson H, Karlsdottir S, Hjaltadottir S, Olafsdottir U, Thorbjarnardottir B, Skaftadottir T, Sturkell E, Jonasdottir EB, Hafsteinsson G, Sveinbjornsson H, Stefansson R, Jonsson TV (2005) Forecasting and monitoring a subglacial eruption in Iceland. Eos 86(26):245–252
Vogfjörd KS, Hjaltadottir S, Kjartansson E, Roberts MJ (2009) Seismic signals from Eyjafjallajökull and Katla volcanoes, Iceland. The Volume Project, European Commission, 6th Framework Project 'VOLUME', contract 08471
Wilson TM, Cole JW (2007) Potential impact of ash eruptions on dairy farms from a study of the effects on a farm in eastern Bay of Plenty, New Zealand; implications for hazard mitigation. Nat Hazards 43:103–128
Wilson T, Stewart C, Cole J, Johnston D, Cronin S (2010) Vulnerability of farm water supply systems to volcanic ash fall. Environ Earth Sci 61:675–688
Wilson T, Cole J, Cronin S, Stewart C, Johnston D (2011a) Impacts on agriculture following the 1991 eruption of Vulcan Hudson, Patagonia: lessons for recovery. Nat Hazards 57:185–212
Wilson TM, Cole JW, Stewart C, Cronin SJ, Johnston DM (2011b) Ash storms: impacts of wind-remobilized volcanic ash on rural communities and agriculture following the 1991 Hudson eruption, southern Patagonia, Chile. Bull Volcanol 73:223–239
Wilson TM, Stewart C, Sword-Daniels V, Leonard GS, Johnston DM, Cole JW, Wardman J, Wilson G, Barnard ST (2012a) Volcanic ash impacts on critical infrastructure. Phys Chem Earth 45–46:5–23
Wilson G, Wilson T, Cole T, Oze C (2012b) Vulnerability of laptop computers to volcanic ash and gas. Nat Hazards 63:711–736