 doi:10.20944/preprints202001.0070.v2

Haze, Hunger, Hesitation: Disaster aid after the 1783 Laki eruption

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Abstract

The 1783-1784 Laki eruption was one of the most severe natural catastrophes to occur in Iceland in historical times (since 1140 years). Vegetation damage by sulphate aerosol and fluorine poisoning caused a massive decimation of livestock. The impact of fluorine poisoning and sulphate aerosol on human mortality is uncertain, but the loss of animals caused a famine which took many lives. The vulnerability of the Icelandic society to famine is discussed. 18th Century Iceland was a Danish dependency and, despite the abundance of fish in the surrounding waters, a subsistence farming community and thus highly dependent on livestock. On the other hand, the farming community possessed coping strategies which mitigated the impact of livestock loss. During the famine, the Danish government was in principle willing to provide relief. However, local authorities in Iceland were slow to ask for help, and did not dare to exploit the means at their disposal (e.g. the right to ban the export of Icelandic foodstuff) without consent from Copenhagen. The Danish officials in turn were unwilling to act decisively upon incomplete information. These two factors prevented timely measures. While $4.4 \times 10^5 kg$ of grain were provided for famine relief in summer 1784, the merchants exported $1.2 \times 10^6 kg$ of fish, which greatly aggravated the hunger in the second winter. The effects of this 'natural' catastrophe could therefore have been significantly reduced by efficient government.

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Keywords: Laki, Iceland, volcanic haze, fluorine poisoning, famine, disaster relief

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1. Introduction

The 1783 Laki eruption was, in terms of lava output, the second largest eruption in Iceland since the country was inhabited around AD870. Lasting from June 8th, 1783 to February 7th 1784, it produced about $15km^3$ of lava, covering an area of around $600km^2$, spread fine poisonous ash over most of the island, and produced a persistent sulphurous haze which was observed over large parts of the Northern hemisphere (Thordarson & Self, 1993, 2003). The so-called Haze Hardships (*Móðuharðindin*) caused by the eruption were probably the worst natural catastrophe which befell Iceland, and killed about 1/6 of the human population. However, few, if any, of the deaths were caused directly by the eruption, i.e. by lava streams or tephra fall. Written accounts (e.g. Steingrímsson (1788/1998); Finnsson (1796)) agree that the main causes were famine - brought about by a massive loss of livestock - and non-specified contagious diseases (Hálfdanarson, 1984). More recently, fluorine poisoning and inhalation of volcanic haze have been suggested as additional contributors to human mortality (Grattan et al., 2003; D'Alessandro, 2006; Balkanski et al., 2018). Perhaps remarkably for those times, the government of Denmark - of which Iceland was a dependency - was in principle willing to provide significant famine relief, but on the whole the operation was not successful.

In the English literature, this attempted disaster relief, as well as the influence of the socio-economic background state of Iceland, has received relatively little attention. A milestone contribution on the history of the Laki eruption is the Icelandic volume 'Skaftáreldar 1783-1784' (The Skaftá Fires/Laki eruption 1783-1784), which contains research articles and a compilation of historical letters, mostly reports by Icelandic officials to the Danish authorities (Gunnlaugsson & Rafnsson, 1984). However, since its publication in 1984, much research has been done on the geophysical and climatological aspects of the eruption

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(important publications include Thordarson et al. (2003); Thordarson & Self (2003); Zambri et al. (2019a,b)), its impacts on human health Grattan et al. (2003); Schmidt et al. (2010), but also on the socio-economic situation in Iceland (Gunnarsson, 1983; Eggertsson, 1998; Vasey, 2009).

Combining these strands of literature, the current review article discusses how natural and human factors contributed to the high mortality during the Haze Hardships. The following section (exposure) discusses the volcanic hazards and their direct and indirect effects on human health and mortality, especially the contribution by air pollution and fluorine poisoning. Section 3 (vulnerability) outlines the socio-economic situation in Iceland and investigates vulnerability to famine, and section 4 (capability) describes how Icelandic and Danish authorities tried to cope with the disaster. Section 5 summarises possible long-term effects of the eruption, while section 6 discusses in more general terms the reasons for the meagre effects of relief actions.

Although the article is first and foremost a review on scientific literature, historical sources are used to add some details. Original contributions in this study are the quantification of aid measures in terms of calorie intakes, an estimate of human fluorine intake, and the attempt in the final section to interpret the disaster aid from a risk reduction perspective.

The most important original sources used are: the collection of reports in Gunnlaugsson & Rafnsson (1984), a collection of laws and regulations for Iceland (Stephensen & Sigurðsson, 1854), and accounts by the Icelandic parson Jón Steingrímsson (Steingrímsson, 1788/1998, 1791/2002) and the student Magnús Stephensen (Stephensen, 1785). The reports in (Gunnlaugsson & Rafnsson, 1984, p. 299-417) are letters by Icelandic officials to the Danish authorities, and statements by local farmers (þingvitni), sent in 1784. They will henceforth be referred to as [Rep1784]. For a summary of these reports, sorted by topic, see the Supplementary Material (henceforth referred to as SMx, where x is a section number).

2. Hazard exposure: Fire, Fog and Frost

There already exists an extensive literature on physical aspects of the eruption, including geological, environmental and climatological aspects. These aspects will only be briefly summarised, followed by a discussion of the consequences on the human population, in particular various factors contributing to the high mortality rates, in the light of contemporary records.

2.1. Environmental impact

2.1.1. Local effects: Lava and tephra fall

The eruption took place along a linear vent system of about 27km length which is known as Lakagígar (cones of Laki) and is part of the Grímsvötn volcanic system (Thordarson & Self, 1993). The flood lava eruption started on June 8th, 1783, and consisted of 10 episodes beginning with explosive activity (due to lava degassing) followed by lava flow. The total lava output was estimated to be $15km^3$, covering an area of ca. $600km^2$ (see fig. 1). Although the vent system itself is situated in the uninhabited highlands, lava followed two river gorges into inhabited areas (Steingrímsson, 1788/1998; Thordarson et al., 2003). The first episodes, until about July 20th, occurred on the western part of the vent system and their lava entered the Skaftá river gorge near Hnúta and near Leiðólfsfell (Thordarson & Self, 1993). The river dried up for 3 months (Thordarson et al., 2003), probably due to evaporation, blocking of the river course, or percolation of water through lava, or a combination of those. The lava followed the river bed to the lowlands, where it spread over the pastures and destroyed several farms. Other farmsteads were destroyed by inundation (after tributaries of the Skaftá became blocked by lava), by tephra fall and by sand storms (partly sand from the exposed beds of the dried-up Skaftá river). From August onward, the eruption shifted to the eastern half of the vent system, and the lava followed the Hverfisfljót river, again destroying several farms. The eruption ceased on February 7th, 1784.

In total, 42 farmsteads and cottages ($\approx 0.8\%$ of all Icelandic farms) were given up either temporally or permanently directly because of lava flows (19),

doi:10.20944/preprints202001.0070.v2

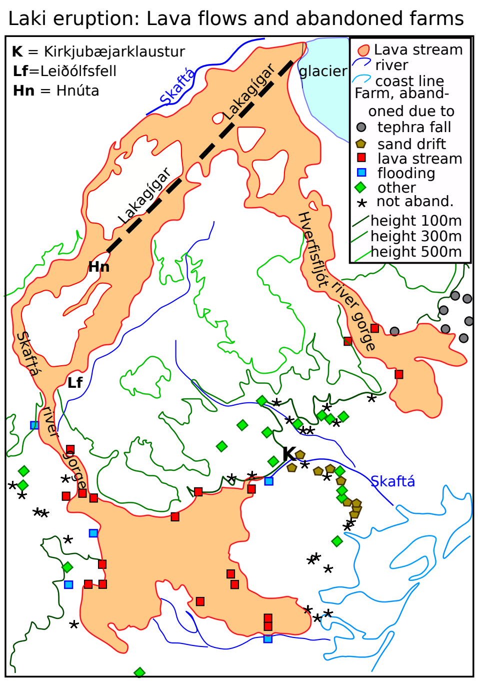

Figure 1: Map of the surroundings of the Lakagígar (based on (Thordarson & Self, 1993, fig. 7) and (Guðbergsson & Theodórsson, 1984, chap. 6.3)).

inundation (5), tephra fall (7) and sand storms (11); another 19 were abandoned for other reasons including loss of animals (Guðbergsson & Theodórsson, 1984). No human lives were taken by the eruption itself, but several hundred persons had to leave their homes. Some of them stayed in the neighbourhood, e.g. on farms given up by their neighbours, while about 500 out of 1964 inhabitants of Vestur-Skaftafellsýsla left the district, mostly moving west, either to other farms or to the fishing districts, e.g. Vestmannaeyjar, Gullbringusýsla (Gunnlaugsson, 1984a). In the two communes closest to the volcano, Leiðvallarhreppur and Kleifahreppur, the number of inhabitants fell from about 1300 in 1783 to 525 in 1784 (Guðbergsson & Theodórsson, 1984), partly due to migration, partly due to death.

2.1.2. Distal effects within Iceland: volcanic haze and fine ash

While the lava was clearly a local hazard, volcanic haze and ash fall affected almost all of Iceland. Only a brief summary will be given; for a thorough assessment including a compilation of translated contemporary observations, see Thordarson (1995). For a map showing districts (sýslur; singular sýsla), see fig. 2.

The Lakagígar magma was rich in gas, including SO2, which reacts in the atmosphere to form droplets of sulphuric acid (H2SO4) (Stevenson et al., 2003), which led to the formation of a thick, “dry”, acidic haze. It was estimated that roughly 120Mt of SO2 were emitted, of which about 80% were carried by eruption columns into the high troposphere and lower stratosphere (9-13km height) (Thordarson & Self, 2003), while about 20% slowly degassed from the lava streams. The latter part of the emission mainly affected southern Iceland, while the former spread widely, transported by high-level winds, and was re-introduced to the lower troposphere by subsidence. In particular, northern Iceland was hit by three waves of strong haze which arrived with northerly, rather than southerly, winds, suggesting that the haze was first transported northward at high altitude, before subsiding and being transported back south at lower levels (Thordarson, 1995).

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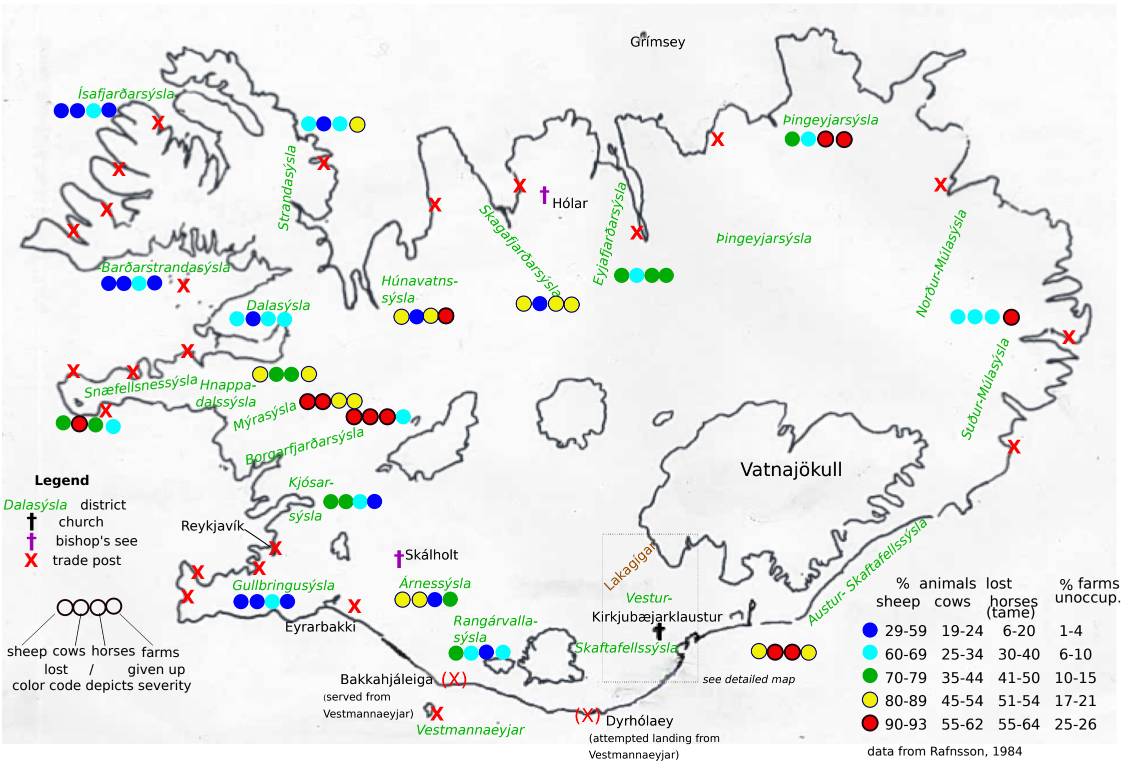

Figure 2: Overview map of Iceland, with districts, trade posts in 1783 (data from Gunnarsson (1983)), and livestock loss and abandoned farms (data from Rafnsson (1984a)). Livestock loss is given as $(N_0 - N_{1785})/N_0 \times 100\%$ where N_{1785} is the number of animals in 1785 and $N_0 = (N_{1703} + N_{1795})/2$. The fraction of abandoned farms is the number of abandoned farms plus cots divided by the total number of farms and cots in 1785 (in Gullbringu-, Kjósar- and Snæfellsnessýsla, only farms are included). Note that Vestur-and Austurskaftafellssýsla are treated as one unit; same for Norður- and Suður-Múlasýsla.

The haze was associated with 'sulphur dust' (deposition of sulphur compounds) and severe damage to the vegetation. Grass whitened, withered to the roots (Steingrímsson, 1788/1998). Grass growth, and hence the hay harvest, was reduced, and it was observed that the hay had less nutritional value, and 1.3-3 times the normal amount was needed to feed the animals (see SM2). The situation was aggravated by the very cold winter 1783-84, which prevented grazing and inhibited grass growth in the following spring, due to frozen grounds. Other plants, including secondary food suppliers like lyme grass, berries, and Icelandic moss, were much diminished due to the eruption (Steingrímsson, 1788/1998; Pétursson et al., 1984). In many locations, fishermen did not dare to go out due to low visibility (see SM4). Many reports also note that the haze caused cold weather as it blocked the sunlight (see SM2).

Strong, low-altitude haze was observed, on and off, in all parts of Iceland during the summer and autumn of 1783 (Thordarson, 1995). Apart from the close vicinity to the volcano, the northern regions (Húnavatnssýsla to Þingeyjarsýsla) report particularly strong effects, especially in mountain valleys, whereas the northwest and part of the west were affected less severely. In Isafjarðarsýsla and Hnappadalssýsla, the reduced grass growth in 1783 is attributed to haze-induced lack of sunshine and cold, rather than poisonous fumes, which may indicate less severe fog at ground level (SM2). Thin, high-altitude haze was observed above Iceland well into 1784 (Thordarson & Self, 2003). In the vicinity of the lava flows, outgassing persisted through 1784, as 'the five largest clouds of smoke and steam [emerging from the lava] did not shrink at all that year' (Steingrímsson, 1788/1998).

Fine ash - produced by lava fragmentation during explosive episodes - spread over an area of $200000 km^2$, including most of Iceland, except the extreme west and northwest (Thordarson & Self, 2003). Although the tephra layer in most regions was not thick enough to physically damage vegetation, the fine ash carried highly toxic fluorine. It has been estimated that about 8Mt of fluorine was released at the vents (Thordarson & Self, 1996). Fluorine can be adsorbed on fine ash particles but is subsequently washed into the ground by rainfall. Comparison with measurements from the 1970 Hekla eruption suggests a fluorine deposition by fine ash of about $9 \times 10^7 kg$ which, when spread over an area of $200000 km^2$, yields $450 mg/m^2$ (Thordarson & Self, 2003)[1]. Assuming a probably optimistic hay crop of $1000 kg/ha$ (Friðriksson, 1972) yields a deposition of $3000 mg/kg$ of hay, although instantaneous concentrations were probably less, because the fluorine was deposited over several months, and meanwhile dilution by rain water or permanent adsorption to the soil (Thorarinsson, 2012; D'Alessandro, 2006) could reduce concentrations. Still, for a sheep weighing 75kg and consuming the equivalent of 3kg of dried grass/day (Sigurdarson & Pálsson, 1957), fluorine intake may have been well above $15 mg/day/kg$(bodyweight), which experiments by (Roholm, 1937, Ch. XXI-XXIV) suggest as an estimate for the lethal dose over periods of half a year (see also sect. 2.2.3).

Livestock was severely affected by the eruption, both through lack of fodder and through fluorine poisoning. A drop in milk production to one-half or even nothing was noticed immediately after the arrival of the haze, in Vestur-Skaftárfellssýsla (Steingrímsson, 1788/1998), but also in the North (see SM3),where the milk yield did not suffice to feed the people, let alone to set aside winter stores. Symptoms associated with fluorine poisoning of livestock (including feebleness, swellings, softened bones, loss of hair) were reported from nearly all over Iceland, except in the northwest (Pétursson et al., 1984), consistent with the spread of fine ash (Thordarson & Self, 2003; Thordarson, 1995) Tooth deformations called gaddur (spike) were observed from autumn 1784 onwards and could occur even years later (Finnsson, 1796). Gas poisoning or inhalation of ash particles may have added to the symptoms (Pétursson et al., 1984). Animals, especially sheep, started to die within two weeks after the onset of the eruption in nearby parishes (Steingrímsson, 1788/1998); elsewhere it took several month for livestock to die (Pétursson et al., 1984). In many regions, animals starved or had to be culled for lack of hay, and in some cases to provide meat for humans, e.g. in Þingeyjarsýsla (see SM2,3).

[1] Thordarson & Self (2003) give $500 mg/km^2$, which seems to entail a typo in the unit.

Rafnsson (1984a) compared the number N of surviving farming animals in 1785 to 'normal' (i.e. the mean of 1703 and 1795), and found a reduction by about 1/2 for cattle and horses and 3/4 for sheep (see table 1 and fig. 2). Apart from the impact of the eruption, this loss also reflects the impact of the previous cold summer 1782, which caused lack of hay and culling of animals in the north and east (Guðjónsson, 2010, Tv_Eyjafjarðar_Dec83)], especially in the northeastern corner of Þingeyjarsýsla (Guðjónsson, 2010), and the effect of the frozen grounds and wet summer weather (especially in the south and west) in 1784, which again led to an insufficient hay harvest and further loss of animals (Guðjónsson, 2010). Incomplete recovery by 1795 can lead to a, possibly regionally dependent, underestimate of the actual loss. The loss of animals was greatest close to the volcano (Vestur-and Austur-Skaftafellssýsla), but also some districts of the west (see fig. 2), while the extreme northwest and southwest were less affected. Within Árnes- and Rangárvallasýsla (Pétursson et al., 1984) and in the north (Thordarson, 1995), inland communes were in general more strongly affected, which may be due to a dominantly northwestward dispersal of the ash and decreasing concentrations away from the source (Pétursson et al., 1984). In coastal regions, animals fared better when fed with seaweed (Steingrímsson, 1788/1998, SM3).

Wild animals, such as fresh water fish and birds, were also reduced (Steingrímsson, 1788/1998; Pétursson et al., 1984), while there is no indication that marine fish was affected.

2.1.3. Pollution outside Iceland and impact on climate

The transport of sulphuric haze was analysed by Thordarson (1995); Thordarson & Self (2003). The haze likely covered the northern hemisphere north of 35°. A thin haze, transported at high altitude by the jet stream, was first noted in central and west Europe around the 17th of June. Six days later, a high pressure system with centre over the Netherlands caused subsidence and introduced large quantities of haze into the lower troposphere. Thick dry mist and sulphur stench were widely observed and debated (Thordarson, 1995; Grattan

	1703	1785 (% of 1703)	1795
Cattle (total)	35860	16592 (46%)	22488
Cows	24467	12898(53%)	15497
Sheep (total)	278994	64459 (23%)	241171
Ewes	167937	43895 (26%)	139125
Horses	26909	12786 (48%)	22599

Table 1: Number of farming animals in Iceland before, 2 years after, and 12 years after the Laki eruption. Based on data from Rafnsson (1984a).

& Brayshay, 1996; Halldórsson, 2013), as the news about the Icelandic eruption only reached the outside world by the end of August. The sulphuric haze caused damage to plant leaves (Grattan & Brayshay, 1996), but no wide-spread harvest failures (Halldórsson, 2013, p. 85 ff). Thick low-altitude haze was present, on and off, until the end of July, and pulses of high intensity occurred through autumn, while the high-altitude (upper troposphere/lower stratosphere) haze remained till early 1784 (Thordarson & Self, 2003).

The Laki eruption was followed by large-scale weather anomalies, including a hot summer in central Europe in 1783, a cold winter in Europe and North America in 1783/84, northern hemispheric cooling for about 3 years (Thordarson, 1995; Thordarson & Self, 2003), and drought in the Nile catchment (Oman et al., 2006a). Several modelling studies have investigated the dispersal and climatic effect of the Laki haze (Stevenson et al., 2003; Highwood & Stevenson, 2003; Oman et al., 2006a; Chenet et al., 2005; Oman et al., 2006b; Schmidt et al., 2010; Pausata et al., 2011; Zambri et al., 2019a,b). The studies reproduce a strong sulphate aerosol haze in the northern hemisphere, both near the surface and in the upper troposphere/lower stratosphere, lasting for several months. Zambri et al. (2019a) showed that some aerosol may have reached the southern hemisphere. The haze lead to a negative radiative forcing anomaly over the northern hemisphere, with peak values for late summer 1783: $-5.5W/m^2$ over the northern hemisphere (Highwood & Stevenson, 2003), $-4W/m^2$ global mean

(Oman et al., 2006b), $-12W/m^2$ over the northern hemisphere, (Zambri et al., 2019b). It cooled the northern hemisphere for several months; peak values for northern hemisphere averages, October 1783: $0.35K$ (Highwood & Stevenson, 2003) and $2K$ (Zambri et al., 2019b). The comparatively weak effect in Highwood & Stevenson (2003) may be due to a low conversion of SO2 to H2SO4. For comparison, the radiative forcing due to the the explosive Pinatubo eruption of 1991 caused a cooling of 0.4K in the global mean (Thompson et al., 2009). D'Arrigo et al. (2011) suggested that the particularly strong cooling in Europe in the winter 1783-84 was possibly due to a negative phase of the North Atlantic Oscillation (NAO) and an El Niño event. However, Pausata et al. (2011); Zambri et al. (2019b) show that the Laki haze may have influenced both the NAO and El Niño. The modelling studies find additional, widespread climate impacts, including a southwards shift in the Intertropical Convergence Zone (Zambri et al., 2019b) leading to drought in the Nile (Oman et al., 2006a), impact on cloud condensation nuclei (Schmidt et al., 2010), and stratospheric ozone concentrations (Zambri et al., 2019a). Unlike suggested by Grattan & Sadler (1999), the observed warm summer 1783 in Europe probably was a coincidence (Zambri et al., 2019b).

Some modelling studies also report surface concentrations of the pollutants SO2 and sulphate aerosol, although different spatial and temporal averaging methods make it difficult to compare the results. For SO2, Oman et al. (2006b) find a concentration of 10-20ppbv ($25-50\mu g/m^3$) at $65°N$, averaged over June-August and $30°W-45°E$, but peak concentrations can have been much higher than this mean. The modelled value is above the EU health guideline (International Volcanic Health Hazard Network (IVHHN)) for annual mean SO2 concentrations (8ppbv). The guidelines also recommend that a daily mean of 48ppbv ($125\mu g/m^2$) should not be crossed more than three times a year. In a modelling study by Balkanski et al. (2018), this value was exceeded for Iceland on 55 days in June-September 1783 (peak value: 113ppbv), but on 0 days in France.

Sulphate aerosol mostly forms particulate matter of diameter $< 2.5\mu m$

(PM2.5). Oman et al. (2006b) finds a sulphate concentration of $8-20\mu g/m^3$ at $65°N$, averaged over June-August and $30°W - 45°E$, while the largest values in Chenet et al. (2005) are $\approx 400\mu g/m^3$ near Iceland and $\approx 40\mu g/m^3$ in northwest Europe, though these may be overestimates as the study assumes a complete conversion of SO2 to sulphate aerosol. Balkanski et al. (2018) model PM2.5 concentrations in June-September 1783 and obtain for Iceland an average daily mean of $34\mu g/m^3$ and a highest daily mean of $148\mu g/m^3$; the highest corresponding values in France are $3.1\mu g/m^3$ and $70\mu g/m^3$ (in Nancy). A threshold of $20\mu g/m^3$ is crossed in Iceland on 70 days within June-September 1783, and in France on up to 3 days. The US health guidelines for PM2.5 (International Volcanic Health Hazard Network (IVHHN)) are a maximum concentration of $65\mu g/m^3$ as daily mean and $15\mu g/m^3$ as annual mean. However, Schmidt et al. (2011) find that a Laki-style eruption in present-day conditions would increase the mean PM2.5 concentrations over the first 3 months after the eruption by $> 100\mu g/m^3$ in the south of Iceland, $50-100\mu g/m^3$ in the rest of the country, $20-30\mu g/m^3$ for England and $10-20\mu g/m^3$ in France, i.e. a stronger effect than the results in Balkanski et al. (2018) (unless industrial and volcanic contributions interact nonlinearly).

2.2. Human mortality

The contemporary treatise by bishop Hannes Finnsson (1796) considers hunger and contagious diseases the main drivers for human mortality after the eruption. More recently, inhalation of gas and acid aerosol as well as fluorine poisoning have been suggested as significant contributors (D'Alessandro, 2006). Gas and aerosol have also been suggested to have caused excess mortality in Europe (Grattan et al., 2003, 2005; Schmidt et al., 2011; Balkanski et al., 2018).

After outlining the temporal and spatial patterns of mortality, I argue that, while hunger and disease alone *could* explain these data, the influence of pollution remains uncertain.

year	1782	1783	1784	1785	1786	1787
population	48736	48925	44600	39578	38368	38668
deaths	1231	1227	5429	5649	2128	920
births	1229	1371	1104	602	937	1220

Table 2: Population, deaths and births in Iceland, 1783-87. Population is given for the end of the corresponding year. Data from Hálfdanarson (1984).

2.2.1. Mortality data

The number of deaths in Iceland was above normal for 1784-86, especially in the first two years (see tab. 2), but not in 1783. Excess mortality in 1786 can be explained by a smallpox epidemic that started in November 1785 and killed 1500 persons, of which 74 died in 1785, (Finnsson, 1796). It cannot be attributed to the eruption, since smallpox epidemics were common in the 18th century, so we focus only on the period up to 1785. The average death rate for 1778-1782 was 30/1000 (Gunnarsson, 1983), amounting to roughly 1500 persons/year. In 1784-85, 11078 persons died. Subtracting the 74 smallpox cases and the estimated normal deaths (1500 per year) gives 8004 excess deaths (about 16.5% of the 1783 population) that may have been caused by the eruption. Population decrease was aggravated by a reduction of births, particularly in 1785-86.

For understanding the role of air pollution, it is relevant whether any unusual mortality can be detected in the second half of 1783, even if not visible in the national, annual mean. Þingeyjarsýsla suffered the highest mortality anomaly in 1783, namely 150% of the 1778-82 mean (see fig. 3); but elevated mortality there might also be related to the harsh winter 1782-83 (Guðjónsson, 2010), which is reported to have caused death and migration in the north of Þingeyjarsýsla (see SM6). Vasey (1991) analysed 65 parishes for which monthly resolution data was available. For those parishes where data was available for 1783 (the southwest-west and the north), mortality in any month of this year is much lower than peak levels in 1784 and 1785. Mortality in the second half of 1783

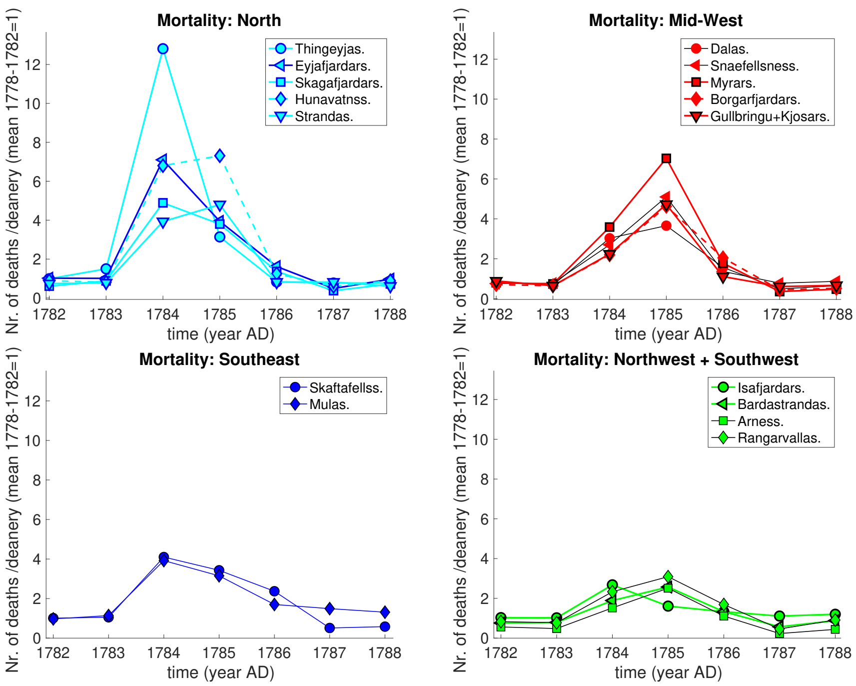

Figure 3: Number of deaths in Iceland, 1782-1788, per deanery, with the mean over 1778-1782 being normalised to 1. Over whole Iceland, the mean over those years was 30 deaths per 1000 inhabitants (Gunnarsson, 1983). Deaneries were roughly equivalent to the districts shown in fig. 2, although sometimes two districts form one deanery (e.g. Vestur- and Austur-Skaftafellssýsla, Norður- and Suður-Múlasýsla). Plots based on data from Hálfdanarson (1984).

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was 18% higher than in the first half[2]. In normal years (average over the four famine-free decades in Vasey (1991)), mortality in July-Dec. is 33% higher than in Jan.-June, with a peak in August-October. When considering only the north (Stranda-to Suður-Þingeyjarsýsla), mortality in July-December 1783 is 32 deaths, 2.3 times as high as for January-June 1783 (14 deaths). The difference is significant at 95% confidence[3]. This could hint at an early impact of the eruption in the north, although when repeating the test on a monthly basis, only December has a significantly elevated fraction of deaths. Unfortunately, no monthly data is available for Vestur-Skaftafellssýsla and the badly-hit north of Þingeyjarsýsla.

A possible concern about the data is that they are based on burials, which may be delayed w.r.t to actual death. There is evidence for such delay in winter-spring 1784. In the north of Þingeyjarsýsla, corpses were left unburied in the church or in farms until June 1784 because survivors were too weakened to dig graves in the deeply frozen ground (seeSM6). Similarly, in Kirkjubæjarklaustur, next to the volcano, 'On certain days [...] numerous bodies would have collected up; sometimes 6, sometimes 8 or 10, were buried in a single grave' (Steingrímsson, 1788/1998, p.78-79), although here the delay may have been in the order of weeks rather than months. Burial delay might help to explain the sharp 'mortality' peak in June 1784 in Vasey (1991) and Hálfdanarson (1984). However, [Rep1784] indicate a warm spell in November to mid-December 1783 (see SM1), which should have provided an opportunity for burials; this would mean that possible delay would concern deaths after mid-December 1783. In addition, the written record from Kirkjubæjarklaustur (Steingrímsson, 1788/1998, p.78-79) mentions that mortality in 1783 was not great, but surged after new year 1784;

[2]Unfortunately, Vasey only gives fractions of the total over 1783-86, not absolute numbers of deaths. The absolute numbers were estimated by assuming the largest common factor (up to rounding errors) to represent one person.

[3]This was tested by comparing the true data to 100000 surrogate data sets, in which 42 deaths are distributed randomly over 12 months with the same probability as Vasey's famine-free decades

in Þingeyjarsýsla ‘people began to die from hunger shortly after new year and continued to die the whole winter, spring and until now [Sept. 16th, 1784], though less widely in the last two months’ see SM6. Conceptions (births - 9 months) were below normal from the beginning of 1784 through the first half of 1785 (Vasey, 1991), supporting the notion of severe hardships from winter 1783/84 onwards.

Investigating mortality in 1784-85, Hálfdanarson (1984) divided Iceland in four regions, ‘north’, ‘mid-west’, ‘northwest and southwest’, and ‘southeast’ (see fig. 3) and assessed seasonality of deaths, based on monthly data from 26 parishes (8% of the Icelandic population). The north suffered very high mortality in 1784 (3.9-12.8 times as high as normal) and high (3.1-7.3 times normal) mortality in 1785; in both years, mortality peaked in spring, the season of lowest food supply. The west experienced moderately elevated mortality in 1784 (2.2-3.6 times normal) and high mortality in 1785 (3.7-7.0 times normal); no peak occurred in 1784, but mortality increases through summer and autumn to peak in winter-spring 1785. In the northwest and southwest, overall mortality was lowest (1.5-2.7 and 1.6-3.1 times normal in 1784 and 1785, respectively), with a maximum in late 1784/early 1785. In the southeast, mortality was somewhat higher (3.9-4.1 and 3.2-3.4 times normal), with no seasonal data. Vasey (1991) with his larger data set (65 parishes) broadly confirms the seasonal patterns and finds that spring peaks in 1784 and 1785 were also present in Norður- and Suðurmúlasýsla. It should be noted that the data provide the location of death, not the origin of a person: A fugitive dying in a foreign district would be listed in that district. The population loss in the hardest-hit districts is therefore likely underestimated.

Outside Iceland, excess mortality was observed at least in France and England in summer 1783-summer 1784. For France, Grattan et al. (2005) found a 38% increase above normal levels of mortality in August-October 1783 in 53 parishes, but no strong increase in June and July. Balkanski et al. (2018), using an extended data set, find an increase of 32% for June-September, without specifying monthly resolution. Grattan et al. (2003); Witham & Oppenheimer (2004)

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investigated English parish data accounting for 7% of the population. Both find near-average mortality in June and July 1783, but a strong rise in August (127% of the normal value) and September (158%)[4]. Mortality remained somewhat elevated over the next months and peaked again in January-February 1784; this second peak might be attributed to the severe winter (Witham & Oppenheimer, 2004).

2.2.2. Hunger and contagious disease

In the parishes analysed by Hálfdanarson (1984), 959 deaths occurred on 1784-85. Of these, 174 were attributed to hunger and 233 to 'landfarsótt', which literally means 'land-travelling disease' and seems to have been used rather undiscriminatively for many endemic, contagious diseases, but not distinct epidemics like smallpox (Hálfdanarson, 1984). Other causes of death include hunger-sensitive diseases like scurvy (11 cases), diarrhea (26), but also accidents, old age, and infant mortality. 341 deaths are marked as 'other and unknown'. In the north, hunger was the most frequent attributed cause of death, and landfarsótt occurred relatively scarcely. In the west, both hunger and landfarsótt were common, while in the northwest and southwest, only one case of starvation was recorded, but landfarsótt did occur.

Hunger as main cause of death in the north would be consistent with the fact that mortality peaked not immediately after the eruption, but in spring, when food was used up. Although the milk production dropped dramatically with the arrival of the haze, Danish grain, fish, moss, and the meat of culled animals provided some food for the first few months (see SM6).

Landfarsótt raged mostly in autumn 1784 and spring 1785 and was most prevalent in the west. The connection between landfarsótt and hunger is subtle. As Hálfdanarson (1984) point out, they not only have different temporal and

[4] Grattan et al. (2003) gives 169% of the normal mortality for July-September 1783 in table 2 and the main text. However, this is inconsistent with the monthly values in the same table, which indicate a value of 128%. This value does appear in their fig. 2.

spatial patterns, but landfarsótt attacked all social strata, whereas hunger especially affected the poorest (vagabonds, paupers, farmhands), and landfarsótt especially killed the very young and the elderly, while hunger deaths were more evenly distributed over all age groups. Thus, landfarsótt was probably not merely deficiency diseases connected to malnutrition (such as scurvy).

On the other hand, it is known that during famines seemingly unrelated (endemic) diseases also surge, due to impaired immune resistance or indirect factors, such migration and deteriorating sanitary conditions, and these diseases may also attack those with sufficient resources to avoid starvation (Ó Gráda, 2007). Even though starvation was not frequent in the west of Iceland in spring 1784, people suffered hardships. For example, the district commissioner Jón Arnórsson of Snæfellssýsla, a district in western Iceland with good fishing grounds and some farms, wrote that the district had lost considerable amounts of livestock and 45 farms had been given up as farmers fled to the coast to save their life by fishing (see SM8). The fishermen also suffered, because they could not exchange part of their catch for farming products (butter, wool) and had to live on fish alone. A second problem in Snæfellssýsla was the fugitives from northern and southeastern Iceland who flocked to the fishing districts - "a few hundred poor people [...] of both sexes and all age groups, no small burden to this district [Snæfellssýsla]" (Rep1784; SM8) - probably leading to cramped accommodation, which together with the generally poor and unhygienic housing (Magnússon, 2010, p 48ff) may have facilitated the spreading of diseases. It is therefore possible that the famine was the main driver of landfarsótt.

Regional differences in animal loss (see fig. 2) were an important, but not the only factor in determining human mortality. Animal loss, and loss of milk production in summer 1783 was very high in the Skaftafellssýslur (Steingrímsson, 1788/1998), where recorded mortality was not particularly high. However, persons that fled these districts and died elsewhere do not appear in this count. For the region closest to the eruption (Fljótshverfi, Síða, Landbrot), the death toll including fugitives was high: 224 out of 602 former inhabitants (37%) died (Steingrímsson, 1788/1998; Pétursson et al., 1984). The very high death toll in the north cannot solely be explained by the loss of animals, which was high, but not exceptionally high. Additional factors might include a stronger drop in milk production in summer-autumn 1783 and the cold winter 1782-83, which had exhausted hay and food reserves and already killed some animals (see SM2,3,6), so that low milk yield per animal and low number of animals coincided in the north. Poor access to alternative sources of food, in particular fisheries Gunnarsson (1980); Ogilvie & Jónsdóttir (2000), may have contributed as well. A higher human exposure to pollutants has also been suggested Schmidt et al. (2011). The mid-west region (Kjósar- to Snæfellssýsla) experienced high losses of livestock, but mortality, only surged from autumn 1784 onwards, i.e. there was no wide-spread starvation in spring 1784 as in the north, possibly because of milder winter weather in 1782-83 and better fishing [SM1,4]. As outlined above, disease played a significant role in the west after summer 1784.

Three regions experienced a relatively minor loss of sheep and cows: the northwest, Gullbringusýsla and Norður- and Suður-Múlasýsla. Of these, the northwest suffered little human mortality, with the exception of Strandarsýsla. The high fraction of abandoned farms in that district (see fig. 2) might partly be due to the proximity of the fishing districts which enabled migration. In Gullbringusýsla, mortality in 1785 was significantly higher than in the northwest (except Strandarsýsla). Both hunger and landfarsótt did occur (51 and 95 deaths, respectively, in the Hvalsnes living (Hálfdanarson, 1984)). The district received a considerable number of fugitives (see SM8), including 148 from Vestur-Skaftafellssýsla Gunnlaugsson (1984a), and 61 out of 166 deaths in Hvalsnes in 1785 were from outside the region (Hálfdanarson, 1984). Thus fugitives increased the mortality statistics, both directly (by dying in the district) and possibly indirectly (competing for fish and good from the trade posts, see SM7,8). In Norður- and Suður-Múlasýsla, Vasey (1991) finds that mortality peaked in spring 1784 and spring 1785, suggesting hunger as a main driver, despite the relatively modest loss of animals. The number of abandoned farms was the highest in Iceland (25.7%), possibly in part due to migration. Like the north, Norður- and Suður-Múlasýsla had experienced a harsh winter in 1782-83

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and had poor access to fishing.

Hunger and disease as main driver of excess mortality *could explain* the features of human mortality, including timing (sect. 2.2.1). This does not prove that they actually *were* the only significant drivers. 36% of the deaths in 1784-85 in Hálfdanarson (1984) are ascribed to 'other and unknown' causes. This could be due to incomplete record keeping, but also due to distinct additional drivers of human mortality that were not recognised at that time, for example, fluorine poisoning and air pollution. The fact that the social status of 228 out of 959 deaths is 'other and unknown' might suggest that record keeping was indeed not complete, but this may not explain all 'unknown' deaths.

2.2.3. Fluorine poisoning

Although fluorosis in humans due to volcanic eruptions is uncommon, it has been suggested that fluorine poisoning occurred after the Laki eruption (D'Alessandro, 2006).

Humans might have inhaled fluorine or ingested it in water or food. Fluorine poisoning would likely have occurred with a delay at least as long as in case of the grazing animals, i.e. several months except close to the volcano, which would be consistent with the timing of mortality. There are several reports that humans suffered diseases resembling those observed in livestock. The farmers in Þingeyjarsýsla, after describing the 'bone sickness' (fluorosis) in animals, report that humans also displayed symptoms, in particular, feebleness and swellings, and some died from it (see SM5). Some witnesses say that it is difficult to decide whether 'bone sickness' or hunger were the causes. The district commissioners in Mýrarsýsla and Borgarfjarðarsýsla state that humans suffered of 'an unusually severe scurvy' that had 'attacked nerves and bones and here and there killed persons. The same illness, but still more severe, has attacked the animals...' (see SM5).

The connection between scurvy and fluorosis is interesting. Sheep, cattle and horses are not susceptible to scurvy, as these animals produce their own vitamin C. The fact that the quoted letters and Finnsson (1796) consider scurvy as a possible disease in animals indicates that scurvy and fluorosis were easy to confuse. In the detailed descriptions by (Steingrímsson, 1788/1998, p. 77-78) and (Stephensen, 1785, p. 128 ff), some symptoms in humans resemble symptoms found in fluorine-affected animals (e.g. loss of hair, swellings) and might thus suggest human fluorine poisoning, but can also be explained by scurvy (Roholm, 1937, Ch. XXVIII.1). Other classical scurvy symptoms like swollen gums and loss of teeth were also observed in humans (Steingrímsson, 1788/1998, p. 77-78) but are unrelated to fluorine poisoning (Pétursson et al., 1984). Scurvy would be likely to occur because of the lack of milk, an important source of vitamin C in the Icelandic diet. It may be impossible to disentangle scurvy and fluorine poisoning as they might interact physiologically, e.g. fluorine might affect the utilisation of vitamin C (Roholm, 1937, Ch. XXVII.5) whereas vitamin C helps to reduce the effects of fluorine (Gupta et al., 1996).

Only 11 deaths out of 959 in the data set of Hálfdanarson (1984) are listed as being caused by scurvy, most of them in Gullbringusýsla, a region with relatively low ashfall exposure, but a diet strongly based on fish, i.e. low in vitamin C. This might simply mean that scurvy was not very wide-spread, or at least it was not (perceived as) the ultimate cause of death. Victims of fluorosis, if any, could have been listed under 'unknown cause of death'. On the other hand, given the similarity of symptoms, one might expect that lethal fluorosis would have been frequently misdiagnosed as death by scurvy. From this perspective, the low number of recorded scurvy deaths suggests a low number of deaths by fluorosis, although it does not exclude non-lethal morbidity.

To complement the historical analysis, I performed some rough estimates of human fluorine exposure. These should be seen as first indications, with room for refinement. First, an estimate of the lethal dose of fluorine is needed. (Roholm, 1937, Ch. XXI-XXIV) induced chronic fluorosis in rats, pigs, calves and dogs. Feeding these animals roughly $15mg/day/kg$(bodyweight) of fluorine caused strong symptoms but was generally not lethal within 1/2 year (with the exception of 1 pig that died on day 171). So $15mg/day/kg$ may serve as an estimate for the lethal dose of fluorine for 1/2 year; for a human weighing

50kg, this equals $0.75g/day$. As an estimate for the lower limit of fluorine intake causing symptoms, Pratusha et al. (2011) states that $10mg/day$ ingested for 10 years or more can cause skeletal fluorosis, and Sigurdarson & Pálsson (1957) found that $20 - 40mg/day$ of fluorine for 1/2 year caused mild fluorosis (slight bone changes) in sheep. As sheep have a similar body weight to humans, $20mg/day$ for 1/2 year will be used as an estimated threshold for mild fluorosis.

Fluorine could have been inhaled, either as HF gas or in fine ash, or ingested with drinking water, meat or plant-based food. I aim to give generous upper estimates of these processes in distal areas, acknowledging that exposure close to the volcano may have been higher. HF concentration in distal volcanic plumes is generally far below health guidelines (International Volcanic Health Hazard Network (IVHHN)) and therefore seems an insignificant source of fluorine. Fine ash can be inhaled while it is falling, but also when it is resuspended by wind. After the Eyjafjallajökull eruption,Thorsteinsson et al. (2012) found PM10 concentrations of up to $1230\mu g/m^3$ (24h mean) in nearby Vík. Ash concentrations in distal areas after the Laki eruption were probably much lower, because only a sub-millimeter ash layer was locally available for resuspension. Humans inhale about $10m^3/day$ of air, which would amount to $12.3mg$ of fine dust inhaled. Allowing for the possibility that some particles up to $100\mu m$ could be inhaled and provide fluorine (even if intercepted in the upper airways) could quadruple the amount of dust, if the grain size distribution in Thorsteinsson et al. (2012) is representative also for Laki ash. But $50mg$ is still much less than the estimated lethal dose of fluorine, even if the particles had consisted *entirely* of fluorine.

Surface water was found to contain 1-9.5ppm of fluorine after a Hekla eruption covering the area with 1-10cm of coarse tephra of a fluorine content of 70-110ppm. Laki tephra was estimated to be richer in fluorine (500ppm, Thordarson & Self (2003)), but the ash layer in distal areas was much thinner and the ashfall spread over a longer time, so 10ppm (10mg/l) seems a generous upper estimate. Milk would have been safe to drink, as fluorine does not penetrate into it (Pétursson et al., 1984). The fluorine content of meat is more difficult to estimate. (Roholm, 1937, p.44) found that the ash of bones of sheep that had grazed near Hekla during the 1845 eruption contained up to 20g/kg of fluorine. In healthy humans, bones contain 99% of the body's fluorine (Zohori & R.M., 2009). Assuming this to hold also for sheep that died of chronic fluorosis, and assuming bones to account for 15% of the body weight (I pessimistically ignore the fact that bone ash weighs less than bone) yields 40mg/kg fluorine in the rest of the sheep's body. So a daily consumption of 3l water and as much as 1kg of meat (30mg+40mg=70mg of fluorine) seems unlikely to cause lethal fluorosis. However, one potentially significant source of fluorine is Iceland moss (cetraria islandica). Although the harvest was severely reduced by the eruption (see SM2,6) some people in Eyjafjarðarsýsla tried to live on 'moss and water' in the summer 1783 (see SM,6). Like grass, the moss could have contained a large amount of fluorine. It is difficult to find nutritional information on Iceland moss, but traditionally, 2 barrels of moss were considered equivalent to 1 barrel of flour (Svanberg & Ægisson, 2012), of which 500g might serve as a meagre daily ration, so 1kg of moss a day might be a reasonable estimate. According to (Rogers, 2012, p.455), 1750kg of dried moss can be harvested per hectar, so 1kg of moss would require about $6m^2$, maybe more since the eruption had reduced the yield. With the estimates from sect. 2.1.2, one sheep would have grazed $30m^2$ per day. So, depending on harvesting and preparation techniques, the fluorine intake of a person trying to live on moss might have been of a similar magnitude, maybe somewhat lower, than that of grazing sheep. However, one can doubt whether many farmers could harvest enough moss to live on it for a sufficiently long period to contract lethal fluorosis; by autumn, the farmers on Eyjafjarðarsýsla were subsisting on meat and spoilt grain from the trade post (see SM6). These tentative estimates suggest that (mild) fluorosis in humans was quite possible, while a major contribution of lethal fluorosis to the mortality crisis of 1784-85 seems doubtful.

Gestsdóttir et al. (2006) performed test excavations on two cemeteries in Vestur-Skaftafellsýsla, Búland and Eystri-Ásar to investigate human bone remains for traces of fluorosis. Only one exhumed skeleton had buried between 1784 and 1845 and may therefore have been affected by the Laki eruption. No

 doi:10.20944/preprints202001.0070.v2

signs of fluorosis were found in that skeleton, thus the result remains inconclusive.

2.2.4. Gas and aerosol

The modelling results discussed in 2.1.3 suggest that health standards for SO2 and PM2.5 (particulate matter smaller than 2.5μm) from sulphate aerosol were exceeded in Iceland and probably also in Europe. Symptoms consistent with high SO2 and sulphate aerosol concentrations were reported in Iceland and Europe. Reverend Jón Steingrímsson, whose parish was closest to the volcano, mentions respiratory disorders such as difficult breathing, especially with persons suffering from pre-existing chest diseases, and irritated throats, skin and eyes (Steingrímsson, 1788/1998, p. 41). Breathing problems in that region persisted at least through spring 1784, possibly due to continuing outgassing from the lava streams. However, Jón Steingrímsson explicitly states that no sudden deaths or mortal illness arose from the bad air (Steingrímsson, 1788/1998, p. 89) in 1783.

The high death rates in north Iceland (a region with high pollution exposure) have been interpreted as indication for a direct contribution of air pollution to human mortality 1783-85 (Schmidt et al., 2011). Respiratory symptoms were recorded in a document from Grund, Eyjafjarðarsýsla (cited in (Thordarson, 1995)). The þingvitni (farmers' statements) in Eyjafjarðarsýsla, Dec. 1783, reported 'disgusting stench and ill odour, such that men with [pre-existing] breast diseases temporarily stayed in bed' (see also SM5). None of these documents, nor any of the letters in [Rep1784], mention any deaths directly connected to these symptoms, or any mysterious increase in mortality in summer-autumn 1783. The overwhelming concern in the þingvitni from Eyjafjarðarsýsla is imminent famine. As outlined above, greater food scarcity can also explain the high death rates in the north. Of course, contemporaries could have misdiagnosed or overlooked deaths by air pollution.

In Europe, symptoms indicating health impacts by the volcanic haze were also recorded; see Durand & Grattan (1999) and references therein. Some contemporary sources in Europe link the haze to illness and mortality (see Grattan et al. (2003) and references therein), although in some of these sources, the wording suggests contagious disease rather than pollution, e.g. 'A fever rages in many parts, which the people term the Black Fever' (Gilpin, England, cited in Grattan et al. (2003)). As outlines above, unusual summer mortality occurred in parts of England and France from August 1783. Grattan et al. (2003, 2005) point out that excess mortality over such a large area suggests a common, probably environmental driver. Clearly, the Laki haze would be such a driver, but so would excessive summer heat. Witham & Oppenheimer (2004) also investigated the hypothesis that the high temperatures in July might have caused the observed mortality in England. They find that high July temperatures tended to be followed by an increase in mortality of around 5%/degree warming in August and September, probably through indirect effects such as fostering disease. However, in 1783, the heat effect only explains 30% of the excess mortality in England, though extrapolation errors might occur. Witham & Oppenheimer (2004); Grattan et al. (2003, 2005) all consider it puzzling that mortality only increased in August, while strong haze had been present from the end of June (Thordarson & Self, 2003), and modern air pollution events (though they may be imperfect analogues to the Laki haze) affect mortality at shorter lags. For comparison, Michaud et al. (2004) found that hospital emergency room visits for asthma and Chronic Obstructive Pulmonary Disease followed exposure to SO2 and fine sulphuric acid aerosol at Kilauea, Hawaii, at lags of only 1-3 days. An additional argument for caution in attributing European mortality solely to the Laki haze is the absence of clear evidence for a major pollution-induced mortality crisis in Iceland in summer 1783. Unless this lack is simply due to gaps in the record, it seems puzzling that France and England should have been more affected than Iceland, where concentrations were much higher.

Comparison with modern events might help to understand the effect of the Laki haze, but quantitative studies of the effect on long-term exposure to strong volcanic pollution are rather scarce (Hansell & Oppenheimer, 2004; Sierra-Vargas et al., 2018). Two studies at Miyakejima volcano, Japan (Iwasawa et al.,

 doi:10.20944/preprints202001.0070.v2

2009; Kochi et al., 2017) found that exposure to average concentrations of up to 45ppb SO2 over 2 years (with 100ppb exceeded 5% of the time and 5-min peaks exceeding 5ppm) were not associated with reduced lung functions, although irritations such as increased cough, throat pain and painful eyes were wide-spread. B.M. et al. (2008) finds that in Hawaii, chronic exposure to SO2, with an average concentration of 49ppb (hourly range: 0–1,700ppb), caused damage to crops and livestock, and increased blood pressure as well as respiratory and eye irritation in humans, but does not report severe illness or increased mortality. For comparison, in the modelling study of Balkanski et al. (2018), 48ppb were exceeded in Iceland on 55 days in June-September 1783, with a maximum daily mean of 114ppb. If the model is correct, then SO2 exposure in Iceland was of similar magnitude as in the Hawaiian and Japanese studies, where no mortality crisis occurred. However, PM2.5 exposure was low in Hawaii and Japan and may have been higher during the Laki eruption.

Schmidt et al. (2011) performed a model simulation to estimate the excess mortality in Europe through PM2.5 in a present-day Laki-style eruption. They predicted 140,000 excess deaths. This is a lower mortality per population than was found for 1783 by Grattan et al. (2003, 2005), but the result can not be directly translated to the 1780s, as it uses different background concentrations (present-day vs pre-industrial). Balkanski et al. (2018) modelled PM2.5 and SO2 concentrations in June-September 1783 over France, using reconstructed weather patterns from 1783, and found that these pollutants cannot account for the excess mortality observed in France that summer. For Iceland, they do find an increase in mortality risk (compared to an unexposed population) by 13-30% from SO2 and about 60% from PM2.5. It is difficult to discern a signal of this magnitude in the Icelandic mortality data for summer-autumn 1783, except maybe the increase in mortality between the first and second half of 1783 in north Iceland. However, the small sample size and generally the strong variability of 18th century mortality in Iceland prevent firm conclusions. Both Schmidt et al. (2011) and Balkanski et al. (2018) point out that major uncertainties arise from the assumed relation between concentrations and mortality. In particular, susceptibility in the 18th century may differ from modern times, e.g. due to lower background exposure and lack of health care.

To summarise, there is ample evidence from historical records for respiratory irritation resulting from the Laki haze, but it is less clear to what extent the haze contributed to excess mortality in Iceland and the rest of Europe. In my view, the hypothesis of a haze-induced mortality crisis should be treated with caution, since correlation is not causation and irritation symptoms not necessarily imply death.

3. Vulnerability: The fish and sheep paradox

In summer 1784, foreign fishing vessels were observed to make good catches on the open sea off Norður- and Suður-Múlasýsla - out of reach for the small boats of most hungry farmers (see SM4). In the same year, the progressive treasurer Skúli Magnússon wrote about the Laki eruption: ‘It looks as if Nature wanted to teach man to show more caution in the future and have better control over his breadwinning’ (cited in Gunnarsson (1984)). Here it will be discussed how the socio-economic situation in Iceland (outlined in sect. 3.1) influenced vulnerability to famine (sect. 3.2).

3.1. Iceland’s socio-economic situation

3.1.1. Absolutist government

Iceland was a dependency of Denmark-Norway, and was ruled from Copenhagen. The administration was ordered in a very hierarchical fashion (see fig. 4), for Denmark-Norway was an absolutist monarchy. All power officially lay with the King by God’s grace. King Christian VII, however, was mentally ill and unable to reign, and de facto the power lay with those who attained control over the king. From 1772, this had been the conservative Ove Høegh-Guldberg, but in April 1784 he was forced to resign after a coup d’état by the sixteen years old crown prince Frederick, who became prince-regent thereafter. Although ‘the Crown’ had to sign most decrees concerning Iceland, the actual decision making was left to lower administrative bodies, especially the Rent Chamber (*Rentekammeret*, the finance department), which issued orders to and received annual reports from the Icelandic officials.

There was no nobility in Iceland. The highest official on the island was the governor (stiftamtmaður); in 1783 the office was held by an elderly Norwegian named Lauritz Thodal, who was regarded a competent, well-willing governor, but was suffering from ill health at the time of the eruption (Stephensen & Sigurðsson, 1854, vol., 4, p. 759). In north and east Iceland he was represented by the deputy governor Stefán Þórarinsson, an energetic young Icelander who had only been appointed to the post in summer 1783, replacing his uncle Ólafur Stephensen. Under them stood the roughly twenty district commissioners (sýslumenn). On an even more local scale, the communal overseers (hreppstjórar) organised local matters, especially poor relief. The clergy (two bishops, about 16 deans, and the parsons) also performed certain administrative tasks, such as keeping parish records and co-organising poor relief.

The Rent Chamber also gave orders to the director and local representatives of the trade company (see sect. 3.1.3), which organised all trade with Iceland and in fact all transport to and from the island. The chief executive, Carl Pontoppidan, was situated in Copenhagen, while the trade representatives stayed in Iceland. It was stipulated that local merchants and Icelandic officials cooperate (Andrésson, 1984; Gunnarsson, 1983). For example, district commissioners had to control the quality of goods, order goods for the following year, discuss with the merchants and inform the Rent Chamber about possible complaints, and supervise emergency loans (see sect. 3.2.4).

Formally, the government system was top-down, Denmark being an absolute monarchy. In reality, Icelandic officials were often consulted by the central government (Karlsson, 2000, ch. 2.12). Still, Stephensen & Sigurðsson (1854) shows that the Danish authorities minutely regulated even minor administrative issues such as the height of contributions to an insurance for widows of Icelandic reverends or funding for repairing old medical instruments (a cost of 11 ríkisdalir 82.5 skildingar, roughly the value of two cows). The instructions for the

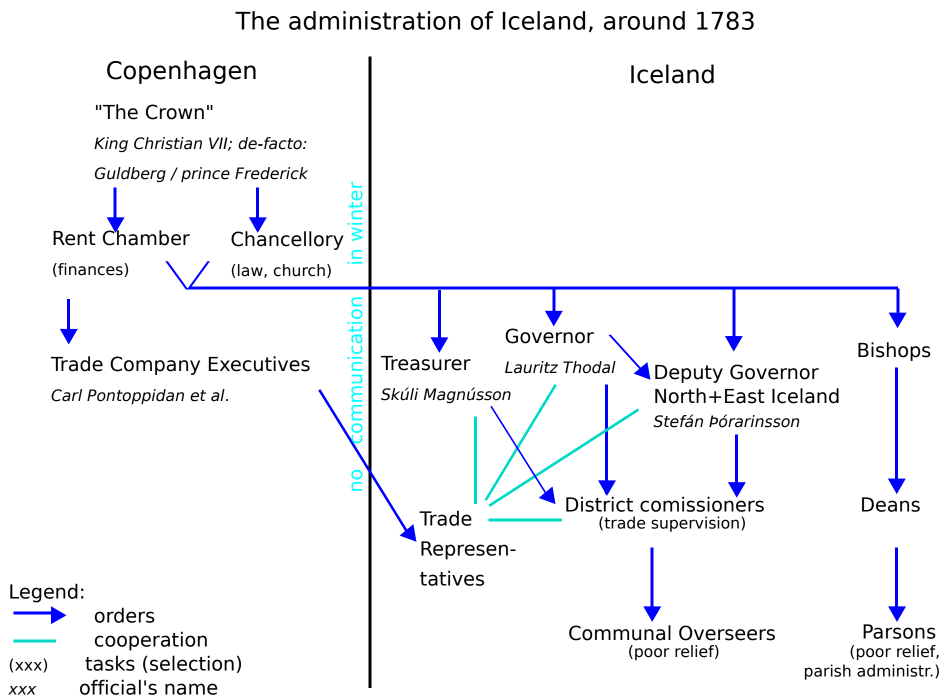

Figure 4: Structure of the administration of Iceland in the late 18th century. The names of the officials are for July 1783-April 1785. Based on (Gunnlaugsson, 1984b; Gunnarsson, 1983; Steingrímsson, 1791/2002, , p. 309ff (comments by translator)).

newly appointed Stefán Þórarinsson (Stephensen & Sigurðsson, 1854, vol. 4, p. 728-740) repeatedly order him to submit suggestions, complaints, or observations to the Rent Chamber. These examples suggest that, while the Danish authorities valued the opinions of Icelandic officials, it also wished to exercise close supervision. Stefán Þórarinsson's orders do not consider the need for independent action in possible emergencies. However, as crossing the North Atlantic in the stormy season was considered infeasible, no communication was possible between Iceland and Copenhagen during the winter, making it impossible for Icelandic officials to quickly consult their superiors in the capital.

3.1.2. Farming and Fishing

The Icelandic economy consisted mainly of subsidence farming, combined with some fishing. There were no urban centres (the largest settlement, Reykjavík, had about 200 inhabitants), and people mostly lived in individual farms. Horses were used for transport; horse-drawn carts, roads, bridges, or inland and coastal shipping hardly existed.

Farming was limited by the harsh climate; grain would not grow, vegetable patches were scarce, and farmers mainly kept cows and sheep for food (mostly dairy), clothes (wool) and light (tallow). Wild food could complement farming products: land-based sources included birds and eggs, lichens (*cetraria islandica*), berries, and freshwater fish, while the sea provided sea shells, seals, and of course fish Hambrecht (2009). Horse meat was usually not eaten Andrésson (1984), due to religious traditions going back to a papal decree of 732AD which condemned its consumption. Neither the reformation around 1550 nor the lifting of the legal ban on horse meat in 1757 put an end to this tradition. In the time between settlement and the Laki eruption, farming had rather become more difficult by slowly progressing soil erosion reduced agricultural land Friðriksson (1972); relatively (though not uniformly) cold climate since about 1200 Ogilvie & Jónsson (2001). It has been argued that certain farming techniques that could have improved farm productivity, like building fences to protect hay land from animals or drainage of marshy land Gunnarsson (1980); Vasey (2009), had been abandoned, possibly partly because short-term tenancy discouraged farmers from improving their land Eggertsson (1998). In the second half of the 18th century, the Danish government tried to (re-)introduce these techniques, e.g. ordering farmers to build fences and level their land (Stephensen & Sigurðsson, 1854, vol. 4, p. 278).

Remarkably, although the sea around Iceland is rich in fish, relatively little use was made of it; fishing remained a sideline, secondary to farming. It has been estimated that about 2/3 of the catch (amounting to 110g of dried fish or roughly 400kcal/person/day) served for domestic consumption and the remainder, mostly high-quality dried cod, was exported (Karlsson, 2000, ch. 2.14). Valuable migratory cod was abundant in the Southwest of Iceland in winter and spring, and in the Northwest in spring (i.e. in a time when there was little farm work). The cool and windy conditions were favourable for wind-drying fish. In the North and East, fishing was possible from spring (if not hindered by sea-ice) to autumn, but had to be interrupted from July to mid-autumn for hay making (Ogilvie & Jónsdóttir, 2000). Farmers in these regions could send their farmhands to the southwest to either participate in the winter fisheries or barter fish for farming products.

Fishing was hampered by technological level (using open rowing boats, rather than decked vessels like foreign fishermen visiting Iceland), and by administrative measures; the formation of fishing villages was prevented by a law prescribing that everybody had to be registered at a farm - either as farmer (owner or tenant) or as farmhand (Gunnarsson, 1983; Eggertsson, 1996) The cited studies suggest several interrelated reasons for the low intensity of fishing: That the Danish crown isolated Iceland from foreign merchants (potential eager customers) for fear of loosing control over the island; that artificially low fish prices (set by the Crown) lowered the incentive for fishing; that most Icelanders lacked the means to invest in more seaworthy vessels; that fishing was considered an insecure source of income, so that unlucky fishermen might overwhelm the poor relief system (sect. 3.2.3); and that the landowning elite and farmers opposed full-time fishing for fear to loose their cheap labourers. These factors kept Iceland in a "poverty trap" of relatively unproductive subsistence farming, underusing its richer resources. Contemporaries such as Skúli Magnússon and some directors of the Monopoly trade (sect. 3.1.3) considered fishing as vital for developing the Icelandic economy. In 1776, it was attempted to stimulate fishing by increasing the fish price and handing out premiums, but at least initially this measure did not entice the Icelanders to do more fishing (Gunnarsson, 1983, p.169). Whether these measures would have stimulated the economy in the longer run if the devastating Laki eruption had not occurred, remains speculation.

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3.1.3. Monopoly Trade

This section is based on the extensive study by Gunnarsson (1983).

Iceland was not a self-sufficient economy: It depended on the import of building wood (for houses and boats), iron (tools) and hemp (fishing lines). Grain was also imported, but in normal years it was a luxury good rather than a necessity. As export goods, Iceland mainly offered wool products, sheep meat and hides, and dried fish. The trade was carried out by merchants or trade companies from Copenhagen who rented the Icelandic harbours from the Crown and had a trade monopoly. From 1774, the trade was carried out by a company run by the Crown, although part of the capital came from private shareholders. Iceland had around 25 trade harbours (see fig. 2), which were mostly visited by one ship per harbour and per year, ships arriving in late spring and leaving in early autumn. In northern Iceland, sea ice occasionally prevented the ships from landing. In 1785, blocking of two harbours likely contributed to the high number of deaths in Húnavatnssýsla that year Hálfdanarson (1984).

Trade was mostly carried out as barter trade, partly because the merchants refused to pay in money, hoping that this would stimulate their customers to also buy luxury goods (brandy and tobacco), which were profitable to the merchants. However, the barter trade made it difficult for the farmers to save money for bad years or even for investing in better fishing boats. All prices were fixed by the Crown. For many decades, fish prices in Iceland were very low compared to prices abroad, making dried fish a lucrative export good for the merchants, but also making the fisheries less attractive for the Icelanders. In 1855, the ban against trade with foreigners was lifted, and in the following decades the fisheries expanded and helped to fuel economic growth Eggertsson (1996); Sverrisson (2002). Whether the same would have been possible in the 18th century, remains of course speculation.

The trade company was the only agency providing transport to and from Iceland, hence it was *the* organisation through which the government could administer relief.

3.2. Resilience to Famine

Jónsson (2009) estimated that male and female farmhands were entitled to rations of 3300 and 2600kcal/day, respectively. Taking into account that children and possibly non-working elderly ate less, I will use 2500kcal/day as a rough estimate for normal average calorie intake. In normal years, Icelandic food production was adequate: During the census of 1703, Iceland had 24467 cows and 167937 ewes. A cow could produce about 1600 litre of milk per year (Jónsson, 2009). If the traditional value ratio "1 cow = 6 ewes" reflects milk production, then milk could have provided 2500kcal/day for 57000 persons (assuming 625kcal/l milk). The actual population in 1703 was only 50358 (Karlsson, 2000, ch. 2.14) and had also access to other food than milk. Nonetheless, devastating famines as well as periods of local distress occurred (Finnsson, 1796). In the following, the Icelanders' possible 'lines of defence' against famine, from household to government level, are briefly discussed.

3.2.1. Population pressure and population control

Bishop Hannes Finnsson (Finnsson, 1796) argued that Iceland was clearly not uninhabitable, for there were enough good years to allow the population to recover from the bad ones. Yet, the population never grew much beyond 50000 in the 18th century, which has sometimes been interpreted as evidence for a maximum carrying capacity of the Icelandic soil. However, Vasey (1991) argues, based on mortality data for 1740-1799, that there was no extreme pressure on food reserves in ordinary years, because mortality did not peak in spring (when food would have been scarcest), except for 6 'bad' years, including 1784 and 1785. The population ceiling was a product of birth control rather than endemic hunger (Gunnarsson, 1983; Vasey, 2009): Acquiring a farm was required for marriage, and since the number of farms was roughly fixed, the number of married couples was limited. This led to high celibacy rates and late marriages. Once married, however, Icelandic women had very high fertility rates (Vasey, 2009). Requiring a farm as base for marriage thus prevented population growth to overstretch the food production of the farming community. On the other hand, the same convention helped to prevent the development of fishing villages and thus limited the access to marine resources (Gunnarsson, 1983; Eggertsson, 1996).

3.2.2. Food production and storage

The strong variability of the Icelandic climate has significant impact on grass growth and hay production. It has been estimated that a temperature anomaly of 1 degree C over October-April (i.e. a very severe winter) reduced grass growth by 30% (Bergthorsson, 1985). Both inadequate grass growth and rainy summer weather reduced the hay crop. Although most winters had mild intervals in which the animals could graze, the hay harvest was of utmost importance to keep the livestock alive. In autumn, after the hay harvest, farmers had to decide how many animals they would try to keep alive over the winter; the rest was slaughtered. If the winter was colder or longer than expected, then a considerable part of the livestock could be lost. Storing extra hay was a potential means to protect livestock against bad weather (or eruptions). However, farmers tended to take considerable risks, often not reducing their herds sufficiently in autumn to get their animals through a harsh winter (Eggertsson, 1998), which could lead to large losses of sheep even under conditions far less extreme than the Laki eruption. In 1784, farmers in several regions regretted not to have reduced the livestock sufficiently in the previous autumn (see SM3), though there exists an example of two unusually provident brothers in Isafjarðarsýsla, who kept a large hay stock and were forced by the district commissioner to sell hay to their neighbours, saving the life of 50 cows.

Food storage or alternative food sources could be used to buffer against loss of livestock. Icelandic farming was centred around preserving food. Steingrímsson (1788/1998) reports that several (wealthy) farmers had more than enough food to last through the crisis of 1783-85; probably even poorer households accumulated some reserve in good years. Several bad years were usually needed cause famine (Finnsson, 1796), so Icelandic households (like in most societies, (Ó Gráda, 2009)) must have had reserves to cope with single harsh years. Icelandic farmers could also fall back on food sources not normally used, for example sea shells Hambrecht (2009), the meat of diseased or culled dairy animals (which fed the people in Eyjafjarðarsýsla at least till December 1783, see SM6),and the normally despised horse meat (although even during the Haze Hardships, some would 'rather die than eating it' (Steingrímsson, 1788/1998, p. 82)). Around Kirkjubæjarklaustur, several seal hunts were organised (Steingrímsson, 1788/1998). On the other hand, extreme hardships could reduce the ability to provide food; for example, people in the north were too weak to mow grass (SM2), and the district commissioner of Snæfellsnessýsla, a main fishing district, complained that several boats in his district could not venture out for lack of healthy men from the north (SM4).

Marine fishing yields were, in general, only weakly correlated to farming yields (Eggertsson, 1998), thus offering an opportunity for risk spreading - provided that sufficient boats and tools were present for additional fishing efforts. After the Laki eruption, the fish itself probably didn't suffer. In summer and autumn 1783, poor visibility hampered fishing in many regions (see SM4), although in Eyjafjarðarsýsla there were farmers who switched to fishing to make up for the lack of milk (see SM2). While especially the north was plagued with sea ice in the first half of 1784, elsewhere fish catches were mixed (see SM4). In the main fishing regions in the west and southwest, the spring fishing was not bad overall, and the Danish merchants were able to buy roughly the average amount of fish in winter/spring 1784 (Andrésson, 1984). Often good and meagre catches occurred in close vicinity (see SM4), so yields could have been higher if the Icelanders had possessed more seaworthy boats to cover greater distances and to follow the fish like foreign vessels did.

To summarise, while many farmers could have been more cautious in protecting their livestock from severe climate fluctuations, they mostly had means to feed themselves in minor to moderate crises. The fisheries surely helped to reduce farming risks Hambrecht (2009), but its potential could have been much better utilised with better technology.

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3.2.3. Distribution and social safety net

At least in principle, everybody in Iceland was entitled to food and shelter (Eggertsson, 1998). Servants were mostly paid in food, shelter and clothes, and working contracts between farmers and farmhands started in the beginning of June (i.e. the busy farming season) and lasted for a year; servants could thus not be turned out in winter or in case of temporary illness. Households with sufficient means were obliged to take in their poor relatives, and poor people without suitable relatives had to provided for by their commune (hreppur). The communes could also support households that were in temporary difficulties.

Food was thus fairly well distributed among farmers, workers, and paupers on communal assistance, although vagrants and beggars also existed. However, this safety net operated only on a local level (there were about 160 communes in Iceland), hence climate or volcanic risks could affect the whole commune and overwhelm the system. After the Laki eruption, several communes had more than two paupers per household, partly because farmers could not afford to hire farmhands, who then became paupers (Finnsson, 1796). In many regions, farmers were forced to give up their farms and become vagrants (see also SM8).

There was no strong relief organisation beyond the local level, except some church charity. The bishops of Skálholt donated 20 ríkisdalir from a 'fund for the poor' to the parishes closest to the Lakagígar (Steingrímsson, 1791/2002, ch. 41) - the value of 20 ewes for a population of several hundred persons. Neither the communes, nor another authority, organised food stores; this would likely have been difficult because building and transport were expensive. The Land Commission of 1770 suggested to build emergency stores at all trading centres to prevent famine. This suggestion was not carried out (Andrésson, 1984); instead, an emergency credit system was decided upon, see sect. 3.2.4.

3.2.4. Trade

Trade can smoothen local food shortages. Domestic trade within Iceland was common, e.g. farming against fishing products. However, under severe distress, it could happen that farmers (or fishermen) had nothing to barter. Transport was also a limiting factor, because overland transport relied on horses (and healthy men), which often lacked during farming crises (see SM7&8). Coastal shipping or navigable rivers hardly existed.

The monopoly trade company both imported and exported food. Grain import averaged 16950 Danish tons or $1.4 \times 10^6 kg$ over 1763-84(Andrésson, 1984), whereas the export of mutton amounted to 3223 barrels ($4 \times 10^5 kg$) around 1770 and dried fish to 8120 skippund ($1.3 \times 10^6 kg$) (Gunnarsson, 1983). As a rough estimate, assuming a population of 50000 and a daily calorie intake of 2500kcal/person, imports and exports amounted to 41 and 47 daily rations, respectively. The export volume can be regarded as the maximum buffer provided by trade: Under the extreme assumption of a distressed population obtaining the imported grain without handing in any of the food products earmarked for export, about 7 weeks of additional food could have been gained with respect to normal years. This would require either the possession of sufficient non-food tradable goods, or cash reserves, or a credit system. Many households lacked tradable goods in bad years. Woollen products were the most important non-food export good, but wool could be scarce when very many sheep were dying, at least in the second winter, after the wool from dead sheep was used up. Cash reserves were scarce; in fact, farmers used to be indebted with the merchants, obtaining goods for credit in early summer and paying with farming products by the end of the year (Gunnarsson, 1983).

The trade regulations from 1776 stipulated that if widespread hunger threatened, the governor, deputy governor and district commissioners could ban the export of Icelandic foodstuff (Andrésson, 1984). In addition, the merchants were obliged, in cooperation with the district commissioners and communal overseers, to give farmers in distress an emergency loan of foodstuff and tools, typically for one year. This rule was clearly meant as a temporary relief measure and did apply neither to officials, who were considered wealthy enough to not need emergency loans, nor to persons considered unlikely to be able to pay back the loan. However, it is doubtful whether this law could have prevented a nation-wide famine, because the trade company did not have significant emergency stores

 doi:10.20944/preprints202001.0070.v2

of food in Iceland, particularly in winter. To make things worse, in early 1783, the authorities in Copenhagen felt that the emergency loans had been abused by persons not deserving them, including officials, and sent stern orders both to the merchants, who should collect outstanding debts and give fewer credits, and to the Icelandic officials to pay their debts and be less generous in suggesting ordinary farmers for loans (Andrésson, 1984).

Increasing food import during a crisis was time-consuming, because shipping between Iceland and Denmark only occurred in summer, i.e. orders could be placed only for next year. In 1774 and 1778, it was discussed whether a Danish ship should annually be sent to Reykjavík in autumn, stay there over winter and return with news in spring (Stephensen & Sigurðsson, 1854, vol. 4, p.107, p.437). These texts do not say whether this was actually done; at least in spring 1784, no ship was sent from Reykjavík to Denmark. In 1787, this postal service was definitely established (Stephensen & Sigurðsson, 1854, vol. 5, p. 432).

3.2.5. Summary

In normal years, food in Iceland was not scarce. Although Iceland's economy in the 18th century has been described as poor, stagnant, and under-exploiting its resources, especially fish (Gunnarsson, 1980; Eggertsson, 1996), the farming society had buffers on the farm and commune level to weather less severe drops in food supply. These buffers obviously helped to reduce mortality during large crises, because the loss of human lives 1784-85 was much less than the loss of farming animals. Tying marriage to acquiring a farm provided an effective birth control and ensured that population did not overstretch the carrying capacity of the land under the existing economic system.

On the other hand, the restriction on household formation, along with the trade system, helped to prevent an expansion of the fishing sector. Whether such an expansion, along with freer trade, would have made the bulk of the population wealthier and increased resilience to famine remains speculation. In an optimistic scenario, the fishing could have led to risk spreading by diversifying the economy, increased trade volume per person, allowed households to build up cash reserves to access food import during shortages, and facilitated domestic trade by providing boats for coastal transportation. In a pessimistic scenario, the fishing sector could have lead to unsustainable population growth by removing the birth control mechanism, disrupted the communal insurance system, and created a class of poor fishing labourers working for low wages without fixed contracts, who might have been at greater risk of hunger than farmhands in the actual subsistence farming society.

4. Capability: Disaster (mis)management

Iceland clearly had insufficient resources to cope with a loss of about half of its cows and 3/4 of its sheep, and the modest means at hand were ill used (see below). Therefore help would have to come from outside - from Denmark. Yet communication between the two countries was difficult, and the Danish authorities, although in principle willing to help, only sent significant relief about 13 months after the eruption.

4.1. Troubled communication

4.1.1. Reports to Copenhagen in 1783

In the vicinity of the Lakagígar, sheep and cows died massively within weeks and thus the threat of a (local) famine quickly became imminent. Reverend Jón Steingrímsson of Kirkjubæjarklaustur, as the dean of Vestur- and Austur-Skaftafellssýsla, reacted quickly and wrote several reports to the bishop in Skálholt, asking for financial aid for himself and other local parsons (Rafnsson, 1984b). On July 4th, he also sent a letter to deputy governor Ólafur Stephensen (who was replaced in mid-July 1783 by Stefán Þórarinsson), which ends with a cautiously worded plea for government help: "May God have mercy upon us [...] and awaken the hearts of the officials so that they report the misery which befell this district to His Royal Majesty, who in His mercy will not let us die from hunger and wretchedness" (Steingrímsson, 1783). Ólafur Stephenson passed this letter on to Copenhagen along with his own report dated August

time	event
1783, June 8th	Onset eruption
1783, July	Letters of rev. Jón Steingrímsson to bishop & deputy governor
1783, end of August	News of eruption reaches Copenhagen (letter from merchant)
1783, Oct. 11th	Investigation ship departs towards Iceland (but hibernates in Norway)
1784, winter-spring	Severe famine in Iceland, worst in the north
1784, January	Money collection in Copenhagen to aid Iceland
1784, February	Eruption ends
1784, April 14th	De-facto regent Guldberg disposed by crown prince Frederick
1784, April 16th	Investigation ship arrives in Iceland
1784, May 14th	Deputy governor asks Danes for fish transport to north & econ. support
1784, July	Emissaries investigate Vestur-Skaftafellssýsla
1784, mid July	Full news of famine reaches Denmark; ca 440,000kg grain sent to Iceland
1784, Aug. 14th	Devastating earthquake in SW Iceland, destroying 400 farm houses
1784, Aug. 26th	Danish ship with orders concerning fish aid sinks off South-Iceland
1784, late summer	1.2 million kg dried fish (≈usual amount) exported from Iceland
1784, autumn onward	infectious disease ('landfarsótt') especially in western Iceland
1785, winter-spring	second hunger winter in Iceland
1785, February	Copenhagen: Commission founded; second money collection decided
1785, June 22	several aid measures decided upon (though with limited success)
1785, summer	improving weather; famine ends
1785, Nov. - 1787, Mar.	small pox epidemic (unrelated to eruption?)

Table 3: Timeline of the eruption and measures taken.

15th (Stephensen, 1783). The governor, Lauritz Thodal, only informed the government on September 16th (Gunnlaugsson & Rafnsson, 1984, comment by editors in section II), because he first wanted to gather more precise information - a serious delay seeing that autumn was approaching and thus the time window for shipping over the North Atlantic was closing. The first news of the eruption received in Copenhagen were not an official report but a few, rather inaccurate remarks in a letter by merchant J.C. Sünckenberg of Reykjavík to the directors of the trade company. His letter, dated July 24th, mentioned the destruction of two churches and eight farms by lava, thick sulphuric haze, bad grass growth and illnesses in grazing animals. It reached the capital at the end of August.

4.1.2. The investigation ship and Danish hibernation

Despite the vagueness of the first reports, the Rent Chamber took action and decided on September 17th to send a ship to Iceland to investigate the situation (Gunnlaugsson, 1984b). The ship was loaded with some grain, and aboard were two emissaries, the young lord-in-waiting and Rent Chamber member Hans C.D.V. von Levetzow "who likely desired soon to take the place of the current governor of Iceland" (Stephensen, 1888, p.229) and the student of law and natural science Magnús Stephensen, a son of the former deputy governor Ólafur Stephensen. They were ordered to investigate how best to help the victims, including fugitives, and which of the damaged farms could be made inhabitable again. In addition, Magnús Stephensen was told to investigate the eruption scientifically, including taking samples with an earth drill (Stephensen, 1785, p.XIV) to search for traces of lignite (to test the contemporary theory that volcanic eruptions were caused by subterranean coal fires). They were also ordered to search and investigate a new island which had formed in spring 1783 off Reykjanes during a submarine eruption. The Danish authorities were anxious to take formal possession of this island to forestall other nations to use it as a base for fishing in Icelandic waters or even break the trade monopoly (Stephensen & Sigurðsson, 1854, vol. 4, p.744ff). They needn't have worried: The island was eroded before anyone found it again (Stephensen, 1888, p.252).

The ship departed another three and a half weeks after the Rent Chamber session, on October 11th. Around that time, further worrying news arrived from Iceland, including Thodal's report and Jón Steingrímsson's letter. The Danish authorities were now convinced that something serious was happening in southern Iceland (but had no idea that the north might also be affected). On October 23rd, the Crown issued an order (Stephensen & Sigurðsson, 1854, vol. 4, p. 763-764) that needy persons in southern Iceland should obtain food from the trading posts without payment, under supervision of governor Thodal. However, this order came too late to be shipped to Iceland before winter, because the investigation ship had already left. The decree of October 23rd also approved a suggestion by Carl Pontoppidan, the executive of the royal Iceland trade, to collect money in Copenhagen to support the Icelanders. The collection was eventually held in January 1784 and yielded almost 10000 ríkisdalir (Gunnlaugsson, 1984b).

Meanwhile, the investigation ship had run into several Atlantic autumn storms. After three attempts to reach Iceland, it took winter shelter near Kristianssand in southern Norway (Stephensen, 1888, p.236-237). Due to the advanced season, no further attempts were made to reach Iceland. The investigation ship departed again for Iceland in early March, carrying part of the collected money (1700 ríkisdalir) for distribution to the farmers from the devastated area. Due to further inclement weather, the ship only arrived there on April 16th 1784.

4.2. Food aid and food trade

4.2.1. Loans and export bans (1783)

Already in his letters to Thodal (Guðmundsson, 1783a, July 26th)) and the Rent Chamber in Copenhagen (Guðmundsson, 1783b, August 2nd)), district commissioner Lýður Guðmundsson complained that the stricken inhabitants ofVestur-Skaftafellssýsla were denied the customary emergency loans at the trade post and asked his superiors to persuade the merchant to hand out foodstuff for the needy. He did not mention any intention to try persuading the

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merchant by himself, even though district commissioners were co-responsible for overseeing the trade. It might have played a role in Lýður Guðmundsson's case that the nearest trading post, Eyrarbakki, was outside his district, in a region less affected by the eruption, making it harder to persuade the merchant of the gravity of the situation. However, many other district commissioners were also unsuccessful in forcing the merchants to give emergency loans (see SM7). This was probably partly due to the recent orders regarding outstanding Icelandic debts (see section 3.2.4). Many Icelandic officials, trying to argue that these orders did not apply in case of actual famine, had a weak position because they themselves were indebted to the trade company and thus at the merchants' mercy, and the merchants were reluctant to disregard the recent letters without consent from Copenhagen (Andrésson, 1984). This consent, of course, could not be obtained with winter approaching.

Similar difficulties arose concerning the ban of exporting Icelandic foodstuff (Andrésson, 1984). The merchants had direct financial interests to export as much as possible from Iceland, because merchants received 1.5% of the value of their exports as top-up on wages and merchants' assistants 0.5%. In late summer 1783, the Icelandic governor and district commissioners did not enforce an export ban. Of course, the crisis had not fully unfolded by then, but the withering of the vegetation and reduced milk production had manifested themselves in many trade districts. As a result of the exports, no significant emergency stores were at hand in Iceland in autumn 1783.

In the course of the winter and spring 1784, the fishing season in southwestern and west Iceland was not bad, and the merchants succeeded in acquiring the usual amount of fish from Icelandic fishing boats: around 1.5 million kg (Andrésson, 1984). In addition, the trade company caught fish with its own vessels. In spring 1784, Thodal banned the export of butter and tallow, but not fish (probably the most desired export good). Stefán Þórarinsson banned the export of all Icelandic foodstuff from his harbours until further notice; the merchants were obliged to sell such goods back to the population for the purchase price (see SM7). But northern and eastern Iceland had only very limited

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fishing and, due to the livestock decimation, also very limited meat products, hence this export ban was little effective.

On the district level, while district commissioners complain about the unwillingness of merchants to give loans, relatively few report having tried to confront merchants or having decreed export bans (see SM7). The district commissioner of Suður-Múlasýsla had forbidden the export of meat and tallow in July 1784, but could only express his hope to the Rent Chamber that the merchants would be held responsible in case they disobeyed. His colleague in Norður-Múlasýsla complained that district commissioners had no legal means against merchants (except sending a complaint to Copenhagen). In north Iceland, 4400kg of dried fish were exported despite the ban (Andrésson, 1984). But there are also examples of compliant merchants who willingly handed out foodstuff, e.g. in Skagafjarðarsýsla (see SM7), and the district commissioner of Rangárvallasýsla organised grain to be handed out to fugitives from Vestur-Skaftafellssýsla (Steingrímsson, 1788/1998, p.80). The success of the emergency loan system thus varied between trade posts, depending on the firmness displayed by the local district commissioners and the cooperativeness of the merchant, and of course on the available stores.

4.2.2. Further communication delays (spring 1784)

As mentioned, the investigation ship (see sect. 4.1.2) arrived in Reykjavík on April 16th. By this time, governor Thodal was aware that the situation was grave in most of Iceland, i.e. over a much larger area than anticipated last autumn. Nonetheless, Thodal hesitated for about two months to send the investigation ship - or some incoming trading ship or the seaworthy vessels which the trade company employed for fishing - straight back to Copenhagen with the bad news.

In northern Iceland, the sea ice blocked the coast until the end of May (SM1,Guðjónsson (2010)), preventing all communication by sea. On May 14th, deputy governor Stefán Þórarinsson wrote a lengthy report [in Rep1784; see also SM] to the Rent Chamber and sent it over land to Reykjavík, hoping that shipping would be possible from there. In his report, he submitted numerous suggestions on how to aid the impoverished and starving population. The most notable short-term measures suggested sending 8000 Danish tons [5] (ca 667,000kg) of grain to North Iceland, and also a shipload of (low-quality) dried fish from the Icelandic fishing regions to the north. Part of the aid measures might be financed by a special tax on luxury goods such as brandy, tobacco, and coffee. In the longer run, the deputy governor suggested the donation of whaling ships, and stimulating employment for those who normally processed wool (which was now impossible due to the loss of sheep), e.g. by regulations against exporting unprocessed eiderdown, which should be processed within the country.

Stefán Þórarinsson's letter reached Copenhagen with the returning investigation ship in July 1784. Thodal's reports (in Rep1784) do not indicate that he was familiar with the content. Either Stefán Þórarinsson did not inform Thodal or Thodal ignored his letter; but certainly Thodal did neither send Icelandic fish to the northern harbours nor decree a full ban on exporting Icelandic foodstuff (Andrésson, 1984).

4.2.3. Flour and fish (summer 1784)

In spring 1784, the ordinary trading ships were sent to Iceland earlier than usual and given strict orders to do everything possible to reach their destination (Andrésson, 1984). Should a harbour be blocked by sea ice, the ship should not return to Denmark but wait in the vicinity for the ice to break. However, no significant additional amount of foodstuff was shipped to Iceland this spring: Compared to the 1764-1784 mean of 16950 tons, 24203 tons of grain were imported in 1784, i.e. 7073 tons above average; but of these, 5300 tons were only shipped after mid-July.

On April 19th, the Crown issued a decree (Gunnlaugsson, 1984b; Stephensen

[5] a grain ton was a volumetric measure, equal to 139 litres. It was specified that 1 ton of grain should weigh at least 83.4kg (Gunnarsson, 1983, p. 41).

& Sigurðsson, 1854, vol. 5, p. 45-46) that Thodal and Levetzow, together with the local administrators (district commissioners, deans and parsons), should collect information about which inhabitants were in need of food aid, and how help could be administered. It was decreed that no food aid was to be handed out unless under the supervision of Thodal or Levetzow. Local administrators were ordered to help with collecting information concerning the needs of the victims of the eruptions for aid (building material, animals, food) and the possibilities to relocate fugitives. The Danish authorities clearly still believed that the catastrophe was only regional, in particular, it did not occur to them that northern Iceland (the region hardest hit by the famine) might be affected at all (Gunnlaugsson, 1984b). Also, the Danish officials apparently considered it essential to collect all possible data on the calamity prior to spending money on aid.

The only aid given in spring 1784 was a financial support for the farmers of Vestur-Skaftafellssýsla. In May 1784, Thodal handed Reverend Jón Steingrímsson 600 ríkisdalir out of the collection money brought by Levetzow, and ordered him to bring this money to the local district commissioner Lýður Guðmundsson, who would distribute it among the needy farmers. However, on his way back, Jón Steingrímsson met several of his parishioners who were walking west in the hope to acquire livestock or means of subsistence, and handed out about 240 ríkisdalir on his own account. This act of disobedience brought about a lawsuit against the dean, although eventually he was condemned only to a minor fine of five ríkisdalir and a public apology (Steingrímsson, 1791/2002, Chapter 42-43).

As mentioned, the news of the devastating famine reached Copenhagen in mid-July 1784. Now that the government had received certainty about the situation, swift action was taken to meet the emergency. On July 21st, it was decided to send 3000-4000 Danish tons of flour to Iceland (Gunnlaugsson, 1984b; Stephensen & Sigurðsson, 1854, vol. 5, p.99-100); by autumn, 5300 tons had been sent (Stephensen & Sigurðsson, 1854, vol. 5, p.106-107). In addition, a letter dated July 17th was sent to Eyrarbakki, decreeing that part of the fish catch from West Iceland (which was of lower quality than the fish of Southwest Ice-

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land) should be transported by the vessels of the trade company to the harbours where the need for food was greatest, i.e. northern and eastern Iceland. Unfortunately, only one of the ships sent to Iceland carried instructions concerning the fish, and this ship was shipwrecked off the coast of Vestur-Skaftafellssýsla, and the letters got lost (Andrésson, 1984). Governor Thodal and the district commissioners in the fishing regions still did not dare to declare a ban on exporting foodstuff without explicit orders from Denmark. Thus in late summer of 1784, the merchants exported nearly all fish they had acquired during the last spring, namely 7558 skippund (=1,200,000kg) bought from Icelanders plus their own catches. No fish transports took place towards the north and east (Andrésson, 1984). In the following winter, another several thousand Icelanders died, for a large part of starvation (or landfarsótt). 1,200,000kg of fish could have provided 2500kcal/day to 50000 persons for about 5 weeks. Meanwhile, the Danish merchants profited considerably less from the fish than expected: Fish prices, which had been unusually high during the American war of Independence, had dropped dramatically after the Treaty of Paris in summer 1783, from 0.17 ríkisdalir/kg (averaged over 1780-82) to 0.12 ríkisdalir/kg (1783-87) (Gunnarsson, 1983, p. 151).

Even the food aid which did reach Iceland was not necessarily effective, especially in the remote areas, due to the lack of horses required to transport food from the harbours overland (Andrésson (1984) SM7). An attempt to ship some grain from the Vestmannaeyjar trading post to Dyrhólaey (see fig. 2) in the particularly remote Vestur-Skaftafellssýsla district was given up due to bad weather. Reverend Jón Steingrímsson complained that it would have been more effective to provide his parishioners with fishing and sealing gear, which would have allowed them to feed themselves to some extent (Steingrímsson, 1791/2002, p. 84-85).

4.3. The second year: Good intentions with meagre results

4.3.1. Total evacuation? (Autumn 1784)

After the bad news of the famine in winter 1783/84, further bad tidings reached the Danish authorities in the course of the autumn: On August 14th, 1784, a severe earthquake had hit the southwest of the island, especially Rangárvallasýsla and Árnessýsla. Although the loss of life had been limited, several hundred farms and about 10 churches had been severely damaged or even completely collapsed (Guðjónsson, 2010).

It has long been claimed in Icelandic history books that the Danish authorities now considered Iceland uninhabitable and contemplated a complete evacuation by relocating the remaining Icelandic population to Jutland in Denmark. However, written protocols do not support this hypothesis, although it remains possible that a complete or at least large relocation has been considered orally and informally (Gunnlaugsson, 1984b). What has been considered officially is moving 500-800 unproductive persons (the elderly and infirm, beggars and orphans) to Denmark. Apparently, this proposal lead to heated discussions in the Rent Chamber in early 1785. Levetzow suggested using the military in case the evacuees proved unwilling, while the high Rent Chamber official Jón Eiríkson (a native Icelander) considered the use of military forces against a peaceful population as a breech of law and pointed out that Iceland had no resources to feed hungry soldiers (Eirìksson, 1984). The whole plan was given up shortly afterwards.

4.3.2. Donations and Debts (1785 and beyond)

In February 1785, a special commission (named 'the later land commission', landsnefndin síðari) was set up to investigate how to restore the Icelandic economy (Gunnlaugsson, 1984b; Stephensen & Sigurðsson, 1854, vol. 5, p. 118-120; 124-127). Among its members were Jón Eiríksson of the Rent Chamber, the executive board or the trade company, and Levetzow, who by then was appointed to replace the retiring Thodal as governor in April.

The commission decided to put an end to the aforementioned evacuation plans (Stephensen & Sigurðsson, 1854, vol. 5, p. 216 ff), and to hold a second collection of money, this time in all market towns of Denmark-Norway (Stephensen & Sigurðsson, 1854, vol. 5, p.123-124). This took several months to organise, but eventually, about 36000 ríkisdalir were collected in 1785 (Gunnarsson, 1983, p.145). Some further aid measures were decided upon and confirmed by royal decree on June 22nd, 1785 (Gunnlaugsson, 1984b; Stephensen & Sigurðsson, 1854, vol. 5, p. 216 ff): Iceland was to be provided with food stores for the winter, and 4 shiploads of fish were to be sent to northern and eastern Iceland and sold to the local population for the purchase price, i.e. without charging freight costs. Farmers in need were to be provided with emergency loans from the trade, but only under careful supervision by the district commissioners. In addition, the trade company should put two ships at the new governor's disposal in case it would prove necessary to ship further goods among Icelandic harbours. Norwegian timber was to be sent to the harbour of Eyrarbakki and handed out to the victims of the earthquake who needed to rebuilt their homes (Stephensen & Sigurðsson, 1854, vol. 5, p. 121-123 ff). Timber and further material for building boats were also to be sent to the fishing districts of Gullbringusýsla and Snæfellssýsla, such that the fugitives from the North and Southeast could settle down as fishermen. Governor Levetzow had to supervise the handing out of the timber. Finally, the Rent Chamber sent orders that spring to the district commissioners to count the population and the remaining livestock. In particular, it should be investigated which farms were in urgent need of additional livestock to remain inhabitable; it was planned to provide these farms with money (from the collection funds) to acquire animals.

Not all of these measured proved as effective as was hoped. The Danes sent almost twice as much grain as usual (32200 rather than 16950 Danish tons), and three (not four) shiploads of fish were sent to the northern and eastern harbours, but no other shipments in between harbours were made (Andrésson, 1984), and there were repeated complaints by the Icelanders that it was difficult to obtain goods at the trade posts, partly because they were badly stocked (Gunnlaugsson, 1984b). Note also that the food aid was not a gift; it was sold (albeit without profit) or handed out as emergency loan to eligible people, i.e. farmers in acute distress who were however expected to pay their debts.

Concerning the timber, it appears that Levetzow was very hesitant to hand it out (even though it was already paid for by the collection money), setting up a complicated bureaucracy for the applicants to prove their need (Andrésson, 1984). At the end, a good part of the timber, both in Eyrarbakki and the fishing districts, was never handed out but remained in the merchants' store and was sold in the course of time as ordinary merchandise. About the boat timber, Levetzow claimed that no new boats were needed because enough people had died the last two years to free up boat places for the fugitives, though it may be that he acted to please incumbent boat owners, who feared that new boats would make it more difficult for them to find labourers for their own vessels (Andrésson, 1984).

In some cases, fugitives were also sent back. For example, 40 paupers who had fled westward from eastern Vestur-Skaftafellssýla, were forced by Levetzow to return to their homes in early autumn 1785. By law, paupers were entitled to poor relief in their home commune. However, the 90 remaining, impoverished inhabitants had no means to provide for the 40 returning fugitives, and even the charitable parson Jón Steingrímsson wrote that nothing could be done but 'simply finding them a place to die' (Steingrímsson, 1788/1998, p. 88). At the end, the parish was saved by an exceptional catch of seals, but the episode clearly illustrates how rigidly authorities applied the law, and that aid was far from sufficient.

Nonetheless, the acute famine ended in summer 1785 (Hálfdanarson, 1984), probably because the weather and the hay harvest were very good that summer (Guðjónsson, 2010). However, many farms still suffered severe difficulties due to lack of livestock (Steingrímsson, 1788/1998, p.87). Already in April 1786 the Crown - under the impression of the past favourable weather and recent losses in the monopoly trade, inflicted by the eruption as well as low fish prices and high grain prices - ordered that fewer credits should be given in Iceland and debts be

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reduced as soon as possible (Stephensen & Sigurðsson, 1854, vol. 5, p. 253-255). These orders were given despite the significant amount of money gathered in the collection in 1785. The collected money remained largely unused and was saved as the so-called 'collection funds' in case Iceland should ever be hit by hardships again. The funds depreciated due to inflation and was eventually used in the 1840ies to construct a high school building in Reykjavík (Gunnarsson, 1983, p.145-146).

The attempt to aid farmers in urgent need for animals to replenish their livestock was not very successful: Not only was gathering the information a slow process, but what was worse, animals were scarce in the whole country, and it was nearly impossible to buy them (Gunnlaugsson, 1984b). A Danish request to England in February 1785 to export some English sheep to Iceland had been refused as the English were keen to protect their wool export (Agnarsdóttir, 1992), and the Danes did not pursue the matter (Stephensen & Sigurðsson, 1854, vol. 5, p. 216 ff). Still, some money (from the collection funds) was handed out to farmers in the following years and may have been of some help, although, as Jón Steingrímsson remarked, 'A great number of farmers and farms could have been restored more quickly if the money, which was given to them for the purchase of livestock, had not been taken back for the payment of rents and other debts' (Steingrímsson, 1788/1998, p.89). The considerable amount of unpaid Icelandic debts with the trade company 1783-88 may have been due not to leniency, but to the fact that many debtors had died of hunger (Gunnarsson, 1984).

5. Recovery and lasting effects of the Haze Hardships

In his treatise on famines in Iceland, Finnsson (1796) wrote that 'Iceland never has been defeated by bad years to that extent, that during better years it could not recover, and feed its children'. This also holds for the Laki famine. Livestock was nearly restored after 12 years (see table 1). The population began to increase again after the smallpox epidemic of 1785-87; more people were born than died each single year from 1787 to 1801, and in the decade 1791-1801 the population increase was 1-2% each year (Gunnarsson, 1983, fig. 2.1). This rapid increase was facilitated by the high fertility of married Icelandic women (Vasey, 2009), and by the requirement of farm possession for marriage, which created a 'reserve' of unmarried labourers who could take over the deserted farms and found a family. In the region near Kirkjubæjarklaustur, 43 out of 47 destroyed farms and 9 out of 14 deserted crofts were eventually rebuilt, in some cases after re-location.

The events of 1783-85 made a small contribution towards urbanisation in Iceland: As the southern bishop's see in Skálholt had been largely destroyed by the earthquake of 1784, the later land commission decided to relocate it to Iceland's largest settlement, Reykjavík, then a village of about 200 people, which became the administrative centre of Iceland in the following years.

Although the old treasurer Skúli Magnússon remarked in 1784 that 'it looks as if nature is teaching the people to show in the future increased carefulness and to have better control over the economy' (cited in (Gunnarsson, 1980)), there was no 'building back better' of the economic system. The farming crisis could have lead to an abandonment of the most precarious farms and the establishment of fishing villages, maybe as a continuation of the (relatively ineffective) attempt in 1785 to provide fugitives the means to settle in southwest Iceland as fishermen (see sect. 4.3.2). However, neither was the vicious circle between poverty and the lack of seaworthy boats broken, nor were the laws changed which forced each individual to be registered at a farm (and helped to prevent the formation of permanent fishing villages). Thus, for the next decades, Iceland remained a subsidence farming community. The most significant economic reform caused at least partly by the Haze Hardships was the abolition of the monopoly trade in 1787/88 (Stephensen & Sigurðsson, 1854, p. 416 ff). This measure was taken not so much to improve the freedom of the Icelandic population, but rather served to save government money: The Haze Hardships and unfavourable price changes abroad had rendered the previous trade company bankrupt (Gunnarsson, 1983, p.148-149). After 1788, the Iceland trade was free for all subjects of the Danish Crown, including the Icelanders themselves. Direct trade between Iceland and foreigners remained forbidden, as the Danes feared that such trade would eventually result in the loss of their sovereignty over the island. On the one hand, this new trade regulation allowed Icelanders to become involved in the trade. On the other hand, during the French Revolutionary Wars, new difficulties arose: Now the merchants were no longer obliged to visit Iceland annually (as had been the case during the monopoly period), they found it more profitable to use their neutral status to trade between European belligerents, rather than undertake the perilous journey to the remote Iceland, so severe shortages loomed there. An Icelandic appeal in 1795 to the Danish authorities to open the Iceland trade to foreign nations was not granted (Agnarsdóttir, 2013, p.27).

The Danish request in 1785 to import English sheep to Iceland had a rather bizarre aftermath, namely repeated attempts by British individuals, most notably Sir Joseph Banks of the Royal Society, to bring about a British annexation of Iceland to free the island from the 'Egyptian bondage' of Danish rule Agnarsdóttir (1992). These events culminated in the farcical 'Icelandic Revolution' of 1809, which did nothing to end Danish dominion, but helped to trigger the British government to magnanimously ensure the provision of Iceland with vital imports, as long as the sea blockade of the Napoleonic wars impeded the Danes from doing so.

In summary, although the Haze Hardships were perceived as a dramatic event and had inflicted much suffering in Iceland, they did not bring a turning point in history.

6. Discussion: Was 'something rotten in the state of Denmark'?

After the previous, mostly descriptive sections, one may discuss in which respects the reactions to the Laki disaster were adequate, or not - and whether any lessons can be drawn from the events. This question will be treated first by briefly examine pre-famine attempts to develop Icelandic economy, which determined the vulnerability to famine (sect. 6.1). Next, the magnitude of the disaster aid expenditure (sect. 6.2) will be discussed, and finally, the way in which these resources were put to use (sect. 6.3).

6.1. Development aid without structural change

Were the Danes to blame for Icelandic poverty and the catastrophic impact of climatic and volcanic events in the 18th century, as the 19th century nationalists claimed (Gunnarsson, 1984; Oslund, 2011, ch. 1)? Surely, Icelandic autonomy had declined in preceding centuries: With the reformation around 1550, the Catholic church had been abolished as authority on the island and much church land passed to the Crown; absolutism was introduced in 1662, and in 1602 the king established the monopoly trade (Gunnarsson, 1983, p. 53) to ensure that only his own subjects would enjoy the benefits of trade with Iceland. Iceland was expected to yield revenue to the Crown. For example, in 1684 the king, short of money after a war with Sweden, thoughtlessly changed the trade price list to the disfavour of the Icelanders, such as to be able to extract higher harbour rents from the merchants; his successor had to revert the change in 1703 after several years of famine in Iceland (Gunnarsson, 1983, p. 55-56). On the other hand, Iceland was maybe not treated worse than the Danish peasantry, let alone Danish colonies. As opposed to the Danish peasants, Icelanders did not live under serfdom (stavnsbåndet) and were not required to serve in the military.

With the age of Enlightenment, Danish treatment of Iceland changed. There were now active attempts to modernise the Icelandic economy. In the 1750ies, the treasurer Skúli Magnússon had persuaded the king to provide capital to develop manufactures in Reykjavík, mostly processing wool; the project failed due to, amongst other things, lack of inner-Icelandic markets for its products (farmers weaved their own cloth) and quarrels with the monopoly traders who refused to export the manufactured goods. In the following decades, the Danish government and Icelandic officials made some efforts promote development Oslund (2004), although these mostly aimed at incremental improvement within the

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subsistence farming system rather than structural change. Attempts to stimulate fishing were almost bound to be unsuccessful due to the laws restricting free labour; inconsistently, these laws were sharpened rather than abolished in early 1783 under the pressure of the landowning elite Gunnarsson (1983). Maybe the optimistic officials underestimated the difficulties of 'developing' a backward economy from behind a clerk's desk, with insufficient understanding of the societal fabric. The modern aim of (economic) 'progress' was only beginning to emerge in Europe (Ferguson, 2018, chapter 2) and was slower still to penetrate Iceland's rural, pietist community. Danish policy since the reformation had contributed towards reducing Icelandic autonomy and sustaining the poverty trap of rural subsidence, and the benevolent, but inconsistent 'development aid' bestowed by optimistic enlightened rulers in the second half of the 18th century failed to bring about a structural change and improve prosperity and hence (possubly) resilience to famine.

6.2. Greedy or generous? The magnitude of Danish aid

Over the years 1783-87, the Danish Crown supported the trade company with 76209 ríkisdalir to finance emergency grain import to Iceland (and, to a much lesser extent, the Faroe Islands). In addition, the trade company incurred losses of about 460000 ríkisdalir with the Iceland trade in 1784-1788, which hit both the Crown (ca. 260000 ríkisdalir) and private shareholders (Gunnarsson, 1983, p.142,144). It has been argued that these losses can partly be seen as indirect aid (e.g. unpaid Icelandic debts), while a substantial part of these losses was also caused by changing market prices outside Iceland and liquidation of the company 1787-88 (Gunnarsson, 1983, p.146 ff). The money raised during the collections in 1784 and 1785 was about 46000 ríkisdalir in total, but much of it remained unspent.

To assess whether this amount was 'large' or 'small', consider a few comparisons. In the traditional Icelandic price system, one ewe with a lamb cost 1 ríkisdalur and one good milking cow 6-7 ríkisdalir. In summer 1784, ca. 31000 ríkisdalir were spent to purchase and transport to Iceland 5300 Danish tons of flour (Stephensen & Sigurðsson, 1854, vol. 5, p. 215-216), enough to provide 40000 people with 2500 kcal/day for ca. 16 days (assuming 83.4 kg/Danish ton and 3460kcal/kg flour). As this grain was not necessarily handed out for free in Iceland, the actual costs may have been lower than the initial costs of 31000 ríkisdalir. The 1.2 million kg of fish which were exported in summer 1784 would have cost 54000 ríkisdalir in Iceland (abroad, prices were considerably higher). These comparisons show that the government expenditure after the Laki eruption was a significant amount of money by Icelandic standards, but certainly not enough to completely mitigate food shortage during the 1.5 years of the Haze Hardships, let alone to compensate for the loss of livestock (see table 1) and damages to pastures and buildings brought about by the eruption and the subsequent earthquakes. Compared to other Crown expenditures, these relief costs are actually quite modest. For example, in the early 1780ies, the Crown had funded 3 new trade companies, partly with capital from private share holders. When these companies went more or less bankrupt after the end of the American war of Independence, the Crown decided to compensate the shareholders for their lost capital and non-forthcoming profits by paying them 7.8 million ríkisdalir over the next years, 100 times as much as the direct aid for Iceland (Gunnarsson, 1983, p.141). Another, albeit trifling, expenditure may illustrate royal priorities. In normal years, the Crown imported 50 falcons from Iceland, but in early 1785 it was feared that no oxen could be purchased there to feed the falcons during the journey to Denmark. It was thus decided to limit the import to 30 falcons and send 20 living oxen to Iceland, to feed not the starving Icelanders but the royal falcons. The additional costs (including rebuilding the falcon ship to transport the oxen) were estimated to be 1896 ríkisdalir (Stephensen & Sigurðsson, 1854, vol. 5, p. 128-129). These two examples suggest that, given the will, the Danish Crown could have afforded to spend more to save its Icelandic subjects from starvation.

The Danish reaction the Laki eruption has been criticised both by contemporary and later authors, especially by 19th century Icelandic nationalists who considered it a prime example of harmful Danish influence on their island (Gun-

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narsson, 1984; Oslund, 2011, Ch. 1). However, large-scale government relief was by no means the obvious reaction to famine in earlier centuries (Gunnarsson, 1980); this not only holds before the Laki eruption, but also 65 years later, e.g. during the Irish potato famine 1845-49. During that episode, initial (costly but insufficient) relief schemes were gradually abandoned for fear of disturbing the market. Unlike in Iceland 1783-84, this cannot be explained by unreliable transport and troubled communication over a stormy North Atlantic, but rather by a lack of political will: In the 1840ies the 'Laissez-faire' ideology had much influence on policy and government interference was considered harmful since 'if left to the natural law of distribution, those who deserve more would obtain it' (Ó Gráda, 2000, p.6-7). The Laki eruption, on the other hand, took place during a relatively enlightened period in which it was considered good governance to actively foster the economic activity of a country's subjects and to mitigate famine (Gunnarsson, 1984, 1980). Thus, however insufficient, belated and clumsy the Danish aid may have been, one should acknowledge that they at least tried to help.

6.3. A case study in disaster (mis)management?

Why was the disaster relief not more successful? It is interesting to discuss this question from a disaster risk reduction perspective, even though this is 'unfair' in the sense that disaster risk reduction is a fairly modern concept. It should also be acknowledged that the Danish authorities worked under severe logistic constraints. Iceland was a remote dependency which most Rent Chamber members were not familiar with, although one high-placed member, Jón Eiríksson, was a native Icelander. Communication and transport to Iceland were cumbersome and expensive, the duration of a single journey was of the order of 2-3 weeks, and in winter sailing was (considered) impossible. Transport within Iceland was likewise difficult, especially after the massive loss of horses.

The first step to take measures is to detect the threatening disaster and raise alarm. Local authorities in Iceland took a long time to realise that the Laki eruption might have severe impacts beyond the area closest to the volcano. In particular governor Thodal lost crucial time trying to confirm information prior to writing to Copenhagen, for fear of risking a false alarm (see sect. 4.1.1). To be fair, eruptions with such widespread effects are not common in Iceland, and Thodal's residence near Reykjavík was in one of the least exposed regions. The fluorine poisoning of livestock had not fully manifested itself in late summer 1783, although severe withering of grass had been observed throughout most of Iceland. Foreseeing the magnitude of the famine was thus difficult (and remains a difficult issue today, e.g. Hillier & Dempsey (2012)). However, already before before Thodal's report came in, the Danish government reacted to the vague letter by merchant Sünckenberg and decided to sent a ship to Iceland - a considerable expenditure.

One important problem was undoubtedly communication troubles. When the full extent of the famine became obvious in the course of the winter, Iceland had no means to communicate with the outside world. A cautious government could have stationed a postal ship on the island each winter to be ready to sail in spring (see sect. 3.2.4). This way, the news of the famine could have reached Copenhagen about 3 months earlier in 1784, thus significantly enhancing the time window for action before the next winter. Even in summer, sailing to Iceland could be dangerous: The ship carrying orders concerning export bans got shipwrecked in August 1784. Of course, this was partly bad luck, but it was well known that the coast of Iceland was dangerous, so it would only have been prudent to send spare copies of the letters with each of the four ships sent to Iceland in late summer 1784. In other words, communication lines were not only long, but also lacked resilience, and the government did not take into account the possibility of accidents. Of course, the loss of the letters would not have had such ill consequences if Thodal - who by summer 1784 must have been aware of the grave situation in wide parts of the country - had taken more initiative and banned the fish export on his own account.

Communication troubles can be mitigated by other measures. One approach could be to have competent local representatives and to give them wide discretion to implement measures on their own. However, the top-down administra-

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tive system of absolutist Denmark rather stifled initiative. Both local officials (governor, district commissioners) and trade representatives frequently delayed decisions waiting for detailed orders from Copenhagen. This attitude was likely stimulated by the central government (see sect. 3.1.1). Another example is the lawsuit against Jón Steingrímsson (see sect. 4.2.3) who was sanctioned for showing too much initiative by disobeying not the spirit, but the letter of Thodal's orders. Still, the Icelandic officials were empowered by law to supervise emergency loans and decree export bans. Fear for potential frowns of the rent chamber does not absolve them from their responsibility, and it is possible that some of them could have been more active in confronting merchants (see sect. 4.2.1).

Lacking both adequate communication and trust in local representatives, another measure could be to set up in advance well-designed emergency plans which the local authorities simply have to carry out. Obviously, this method requires a deep knowledge of the local situation by the central planners, as well as very clear instructions. The laws concerning possible export bans and loans for needy farmers can be seen as an attempt of an emergency plan (although it would have been more potent if backed up by significant emergency stores on the island). However, when famine loomed, there seems to have been confusion as to what was an 'emergency' and who was 'eligible' for a loan. The Danish government had further undermined its own emergency plan in early 1783 by sending letters concerning the need to reduce Icelandic debts, underestimating the tendency of Icelandic authorities and trade representatives to follow the most recent instructions rather than the overarching goal of preventing starvation. As described in sect. 6.2, the Danish government formulated in autumn 1783 a clarification that loans were still to be given in emergencies, but only after the investigation ship had departed.

Another difficulty diminishing the efficiency of aid were conflicts of interests. The most striking one is the multitude of roles of the trade company. Being the only organisation providing transport to Iceland, and the only owner of significant food stores on the island (at least between the fishing season in spring and the departure of the trade ships in summer), it was *the* instrument through which the government could administer relief. At the same time, the trade company was a commercial enterprise, and both the shareholders (including the Crown) and the employees in Iceland expected to make profit from it. On the Copenhagen end, the Crown could, if it wished, override the shareholders' economic interests and decree that unprofitable rescue actions be carried out. However, the trade representatives in Iceland had a strong financial incentive to export as much from the island as they could, and thus to oppose any attempt by Icelandic officials to ban export. They also refused in some cases to put their large fishing vessels at the disposal of the governor for transporting foodstuff, possibly because they considered fishing more profitable. Maybe the central government did not foresee this problem; at least no reference regarding financial compensation is made in the order of July 21st, 1784 (Stephensen & Sigurðsson, 1854, vol. 5, p.99-100), which (unsuccessfully) ordered that local tradesmen should 'provide their Hukkerter [fishing vessels] to transport fish and other foodstuff from one district to the other' (see sect. 4.2.3).

Finally, while the Danish government was willing to take significant action when confronted with definite bad news, it proved unwilling to do so in view of incomplete information. For example, given the disturbing, but unclear news that had reached Copenhagen by winter 1783/84, the government could have chosen for a 'least regret' option and send a substantial additional amount of grain to Iceland in early spring, even while not being sure whether it would be needed. Of course, this would have been costly in the short run, but if the situation had turned out less serious, the surplus grain could have been stored and less been sent in 1785. The extra cost of sending too much grain in the absence of famine should have appeared much less severe then the loss of human life brought about by not sending the grain in the presence of famine. But instead of acting decisively based on a plausible worst-case scenario, valuable months were spilled waiting for the return of the exploration ship and sending repeated requests to the Icelandic officials in the region nearby the Lakagígar for careful surveys of population, fugitives, livestock etc. In the words of Jón Steingrímsson, who as dean was co-responsible for gathering this information, 'These [census lists] could hardly be expected to make sense or to agree, as people were constantly moving back and forth and some dying' (Steingrímsson, 1788/1998, p. 86). In any way, collecting information in the large, thinly populated Iceland was a tedious business, and the data could be shipped to Copenhagen only with the ships departing in autumn, so that they would be acted upon only in the next year. In spring 1785, renewed requests for a careful survey of livestock and human population were sent to the whole of Iceland, partly to assess which farms were in need of assistance to buy livestock. From many districts, this information was delivered only in 1786. In short, it seems that the Danish government was so afraid to incur aid expenditures that might later prove unnecessary, that it preferred to delay action by a year or more and risk that the aid might come too late to do any good.

If one tries to find one single expression describing the shortcoming of the government response, it is undue *optimism*. The Danish officials hoped that the effects of the eruption would not be too bad, trusted that information from and its own orders to Iceland would be transmitted smoothly, that all (sometimes unclear) orders would be carried out immediately and effectively, with officials and trade representatives functioning perfectly without frictions such as competing interests. Maybe a more efficient aid could have been accomplished if the officials had constantly asked themselves: How can this measure go wrong - and what can be done to mitigate potential failure? But this would have required much foresight, imagination, and an intimate knowledge of the local geographical and societal situation.

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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