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Reconstruction of diffusion processes at different geographical scales: the 1904 measles epidemic in northwest Iceland

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This paper presents a case study in the historical reconstruction of the spatial and temporal links by which an infectious disease spreads through a human population. The choice of area (northwest Iceland), the time (the summer of 1904) and the epidemic (measles) are conditioned by the remarkable richness of the historical records for the events described. These records include descriptive accounts in the form of doctors' reports and newspaper articles, and numerical evidence in the shape of morbidity and mortality records collected by doctors and parish priests. The nature of these sources is discussed and illustrated. The information contained in them is used to reconstruct the spread process at both regional (northwest Iceland) and local scales (two parishes in the centre of the area most heavily affected by the disease). It is shown that the pattern of spread can be interpreted in terms of conventional spatial diffusion models. It also highlights the importance of the networks of social contacts—in this case revolving around a church confirmation ceremony—in producing widespread dissemination of the disease.

Death knocked here once
but has passed on—
long since

Ask no questions—
at the fallen fence.

Þorsteinn Valdimarsson (transl. Alan Boucher), *Waste Lands* (1918)

If the evocation of tragedies is a task for the poet, then their spatial reconstruction is one for the historical geographer. The epidemic of measles which struck the remote farming and fishing communities of northwest Iceland in the summer of 1904 was undoubtedly a tragedy in its range and severity: in the hard-hit areas, two in five people were infected by the virus and, of these, one in sixty died. But it was also a hopeful transition, representing the last of the severe episodic epidemic waves that buffeted the island in the nineteenth and earlier centuries; it preceded the first of the regular but milder waves—that of 1907—which were to pass through the island in the present century.

Although it is generally true that much more is known about the spread of epidemics in Iceland today than eighty years ago, there remain some instances in which the historical record is the more illuminating. The high attack and death

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rates of earlier epidemics in small, closely-knit and isolated communities represented a much more serious threat to life, society and economy than is the case with most modern epidemics of infectious diseases. History shows that, in the past, such epidemics were rare in such communities, and where they occurred they were widely reported in press and correspondence. The detailed information thus collected in Iceland means that the passage of epidemics in the early years of this century can be charted with remarkable accuracy.

In this paper, we present an analysis of the 1904 measles epidemic as a case-study in the historical reconstruction of the spatial and temporal links by which disease spreads through a human population. The main source is the conventional archival one of parish registers, but supplemented in the Icelandic case by unusually complete medical records. In the first part of the paper, we describe briefly the geo-

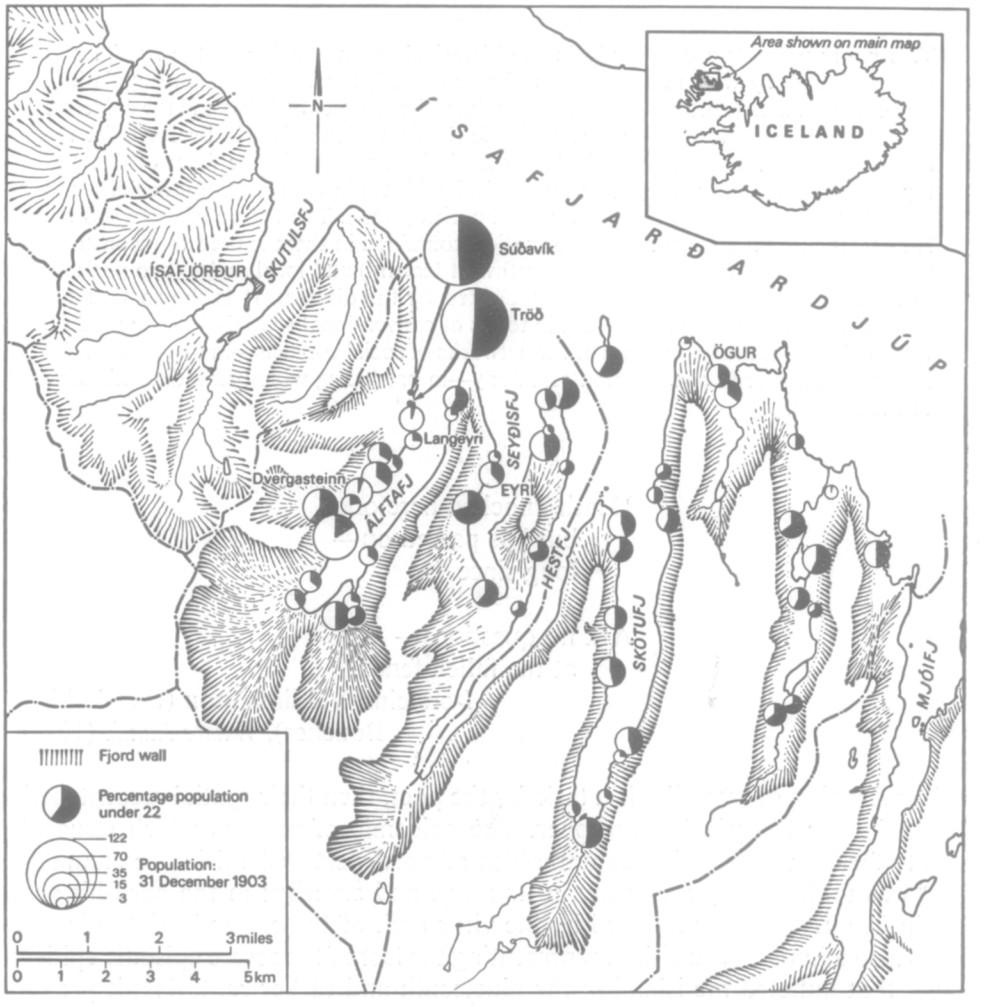


Figure 1. Distribution of settlements in Eyri and Ögur parishes at 31 December, 1903, showing their location, size and age structure. The stringing of the settlements around the fjord edges is striking. Inland from the fjord wall is tableland at an average elevation of c.850 m.

Data source: *Söknarmannatal; Norður-Isafjarðarprófastsdaemi, Ögur og Eyri í Seyðisfirði* (Parish census: North Ísafjörður Deanery, Ögur and Eyri in Seyðisfjörður), 31 December, 1903.

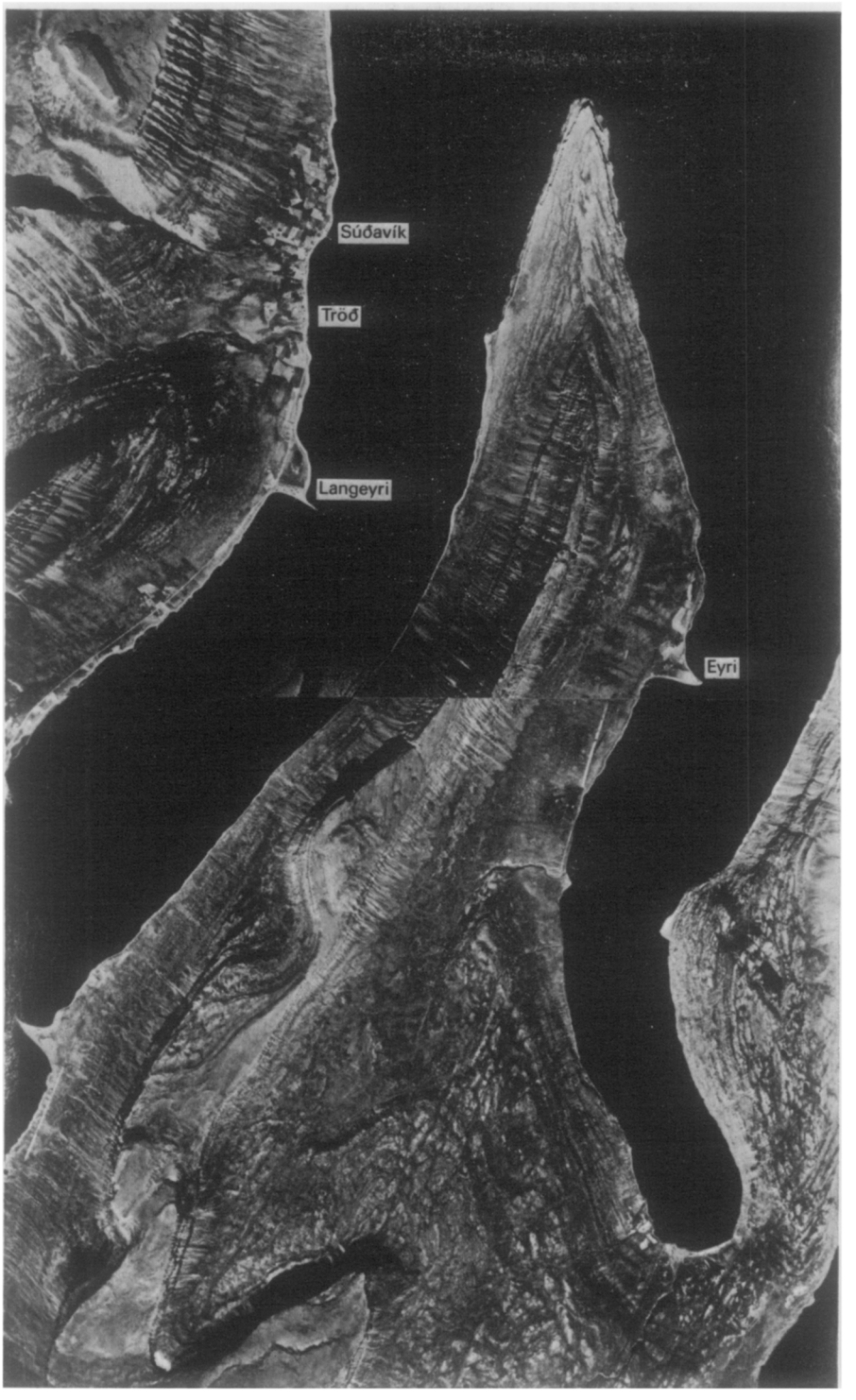


Figure 2. Air photograph of Álftafjörður and Seyðisfjörður in Eyri parish showing the location of the main settlements. "Eyri" is the Icelandic name for spit; "vík" means a bay or cove. The photograph covers the central part of Figure 1.
Source: Air photographs 1196–98, *Landmaelingar Íslands* (Iceland Geodetic Survey), August 1956.

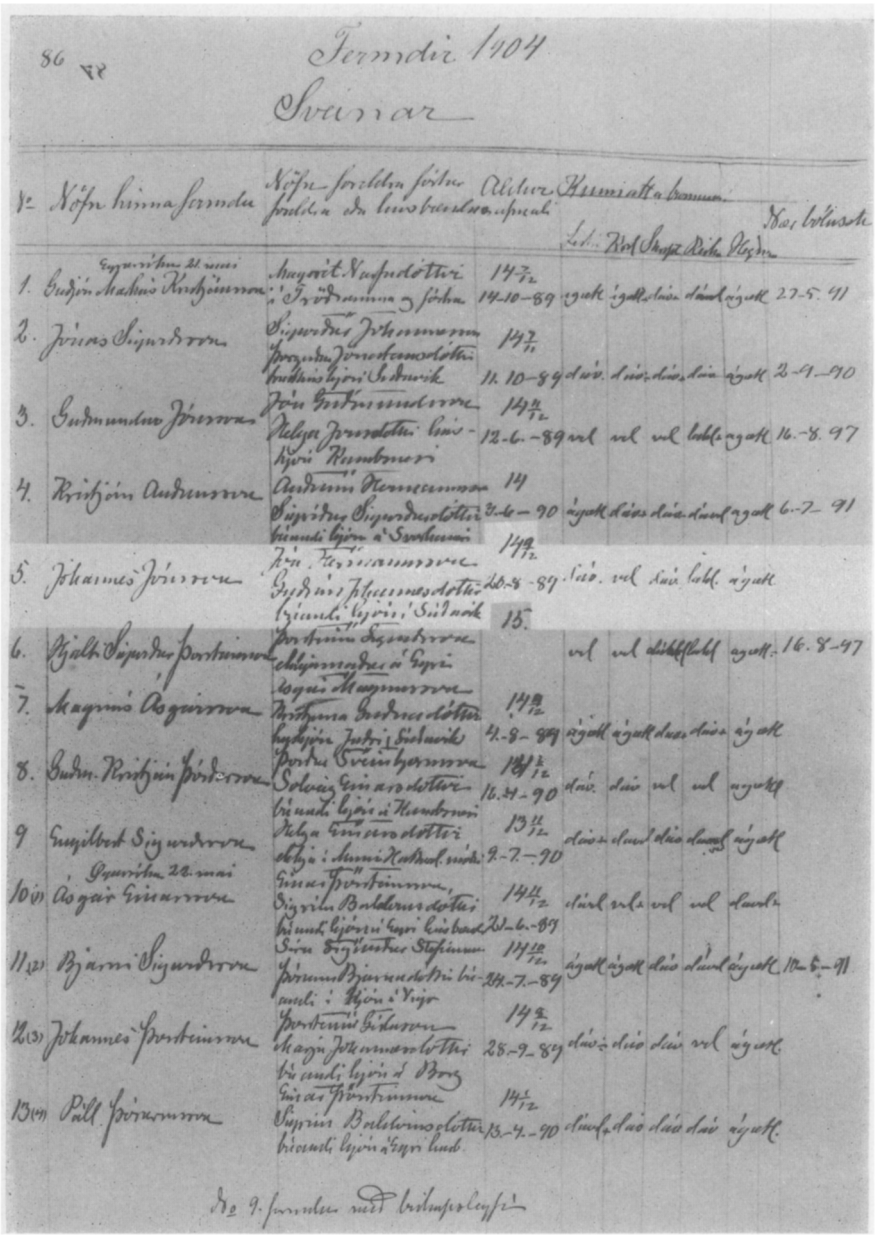
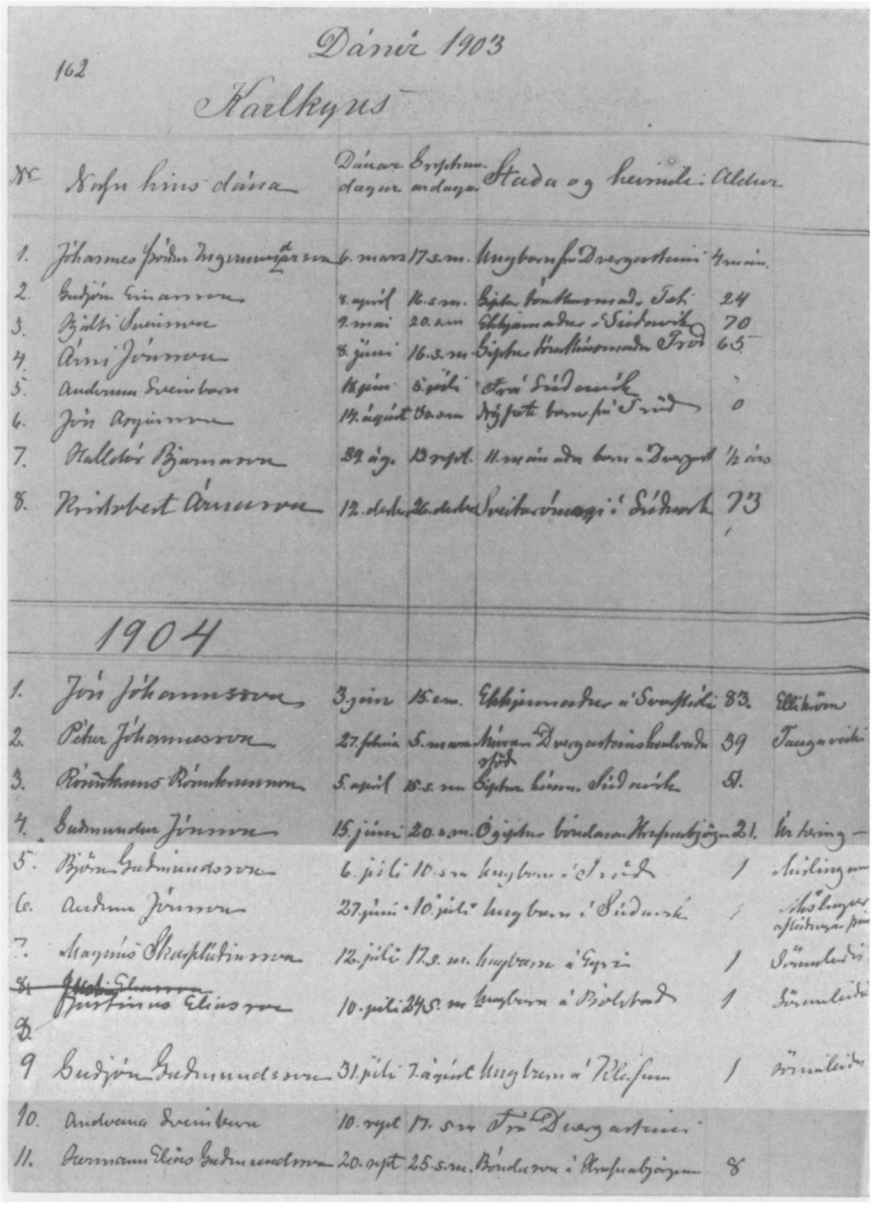


Figure 6. Confirmations in Eyri and Ögur parish churches, 21–22 May, 1904. Page 86 lists boys and page 87 girls. Column headings read (left to right): names of the confirmees; names of parents, foster parents or heads of house; age and date of birth; children's proficiency in reading, Christianity, writing, arithmetic, conduct; when vaccinated [against smallpox]. Male entry 5, Jóhannes Jónsson, has been left unshaded because his brother, Auðunn, died from measles approximately four weeks after the Eyri confirmation ceremony. See male death 6 in Figure 7.

Source: As Figure 4(B)–(D), pp. 86–87.



Deaths (male)

No.	Name of the deceased	Day of death	Day of burial	Standing and domicile	Age	
5	Björn Guðmundsson	6 July	10 same month	Infant at Tröð	1	measles
6	Auðunn Jónsson	27 June	10 July	Infant at Súðavík	1	measles and their consequences
7	Magnús Skarphíðinsson	12 July	17 same month	Infant at Eyri	1	ditto
8	Justinus Eliasson	10 July	24 same month	Infant at Bólstaður	1	ditto
9	Guðjón Guðmundsson	31 July	7 August	Infant at Kleifar	1	ditto

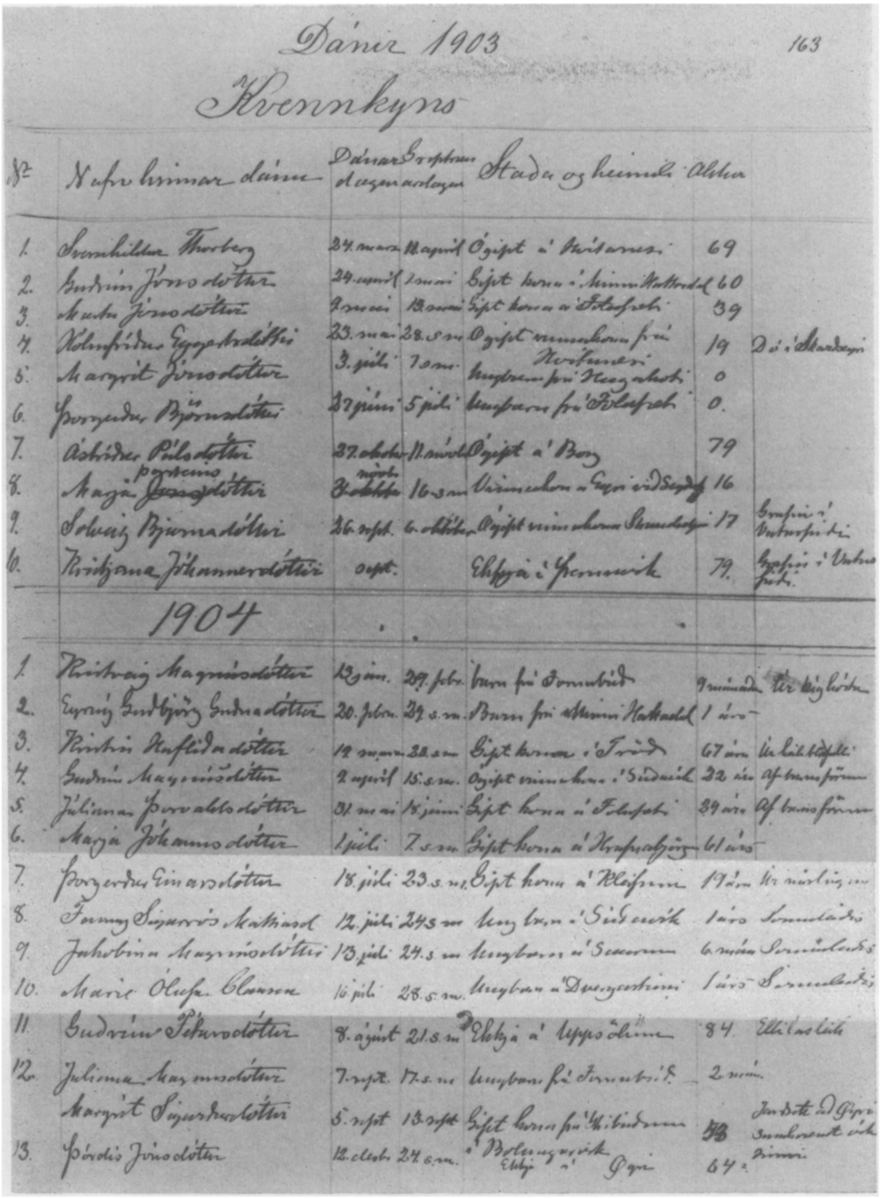
Figure 7. Male and female deaths in Eyri and Ögur parishes, 1903 and 1904. Entries recording deaths from measles are unshaded and translations have been provided. Source: As Figures 4(B)–(D), pp. 162–163.

Fermdar 1904

Meyjar

Nr	Nöfn hinna fermdu	Nöfn foreldra, fósturforeldra og húsbænda	Aldur og afmæli	Kunnátta þeirra: Lestur	Kver	Skrift	Reikn.	Hegðun	Nær bólusett
1.	[illegible] Salome Salomonsdóttir	Salomon Rósenkransson og Sjarlotta Jóns dóttir bústýra á [illegible]	13 10/12 4-8-89	dável	dáv	vel	vel	ágætl	
2.	Hermína Guðrún Sæmundsd.	Bjalti P. Hjaltason Sigríður Bjarnadóttir [illegible] búandi hjón í Tröð	14 4/12 10-1-90	ágætl	ág÷	ágæt÷	dáv	ágætl	27-5-91
3.	Pálína Sigurðardóttir	Sigurður Pálsson Sigríður Rósenkransd. gipt í Tröð	14 7/12 23-2-89	dáv.	vel	vel+	vel	ágætl	4-7-91
4.	Rannveig Guðnadóttir	Guðni Einarsson Rannveig Guðmundsd. faðir og móðir [illegible] í Minni-Hattardal	14 12-5-90	ágætl	dáv	dáv.	dáv.	ágætl	6-7-91
5.	Guðrún [illegible] Einarsdóttir	Guðmundur Jónsson Jónína Jónsdóttir búandi hjón í [illegible] fósturforeldrar.	14 6/12 27-10-89	ágæt÷	dáv÷	dáv	vel÷	ágætl	3-5-91
6.	Guðmunda Sigurðardóttir	Sigurður Stefánsson Ólöf Oddsdóttir [illegible] í [illegible]	14 10/12 11-8-89	dável	vel+	vel+	laklt	ágætl	
7.	Þorbjörg Guðrún Guðmundsd. [illegible] 22. mai	Guðmundur [illegible] Sigríður Jóhannesdóttir [illegible] hjón í Súðavík	14 17-5-90	dável	dáv	dáv	vel	ágætl	1-5-98
8.(1)	Sigríður María Jónsdóttir	Guðni Egilsson og Margrét Jónsdóttir [illegible] hjón á [illegible] húsbændur	14 27-5-90	dável	dável	dáv	vel	ágætl	
9.(2)	Karitas Skarphéðinsdóttir	Skarphéðinn Elíasson Pálína Árnadóttir faðir og móðir búandi hjón í [illegible]	14 5/12 20-1-90	dáv÷	dável	vel	vel	ágætl	
10.(3)	Jónína Guðrún Pálsdóttir	~~[illegible]~~ Páll Jónsson og Ólöf Jónsdóttir búandi hjón á Langabóli	14 6/12 14-12-89	dáv+	dáv+	dáv	dáv.	ágætl	
11.	Elísabet Guðfinna Guðmundsd.	Guðmundur Bjarnason [illegible] Benedikts dóttir búandi hjón í [illegible]	14 7/12 25-4-89	vel+	vel+	laklt		ágætl	
12.	Kristjana Ebenesersdóttir	Ebenezer Ebenesersson Valgerður Guðmundsd. búandi hjón í [illegible]	13 11/12 18-6-90	ágætl	dáv÷	dáv	vel	ágætl	

Nr. 1 og 12 fermdar með biskupsleyfi



Deaths (female)

No.	Name of the deceased	Day of death	Day of burial	Standing and domicile	Age	
7	Þorgerður Einarsdóttir	18 July	23 same month	Married woman at Kleifar	19	of measles
8	Fanney Sigurrós Mattíasd	12 July	24 same month	Infant at Súðavík	1	ditto
9	Jakobina Magnúsdóttir	13 July	24 same month	Infant at Saura	6 m.	ditto
10	Marie Ólafa Clausen	16 July	28 same month	Infant at Dvergasteinn	1 yr.	ditto

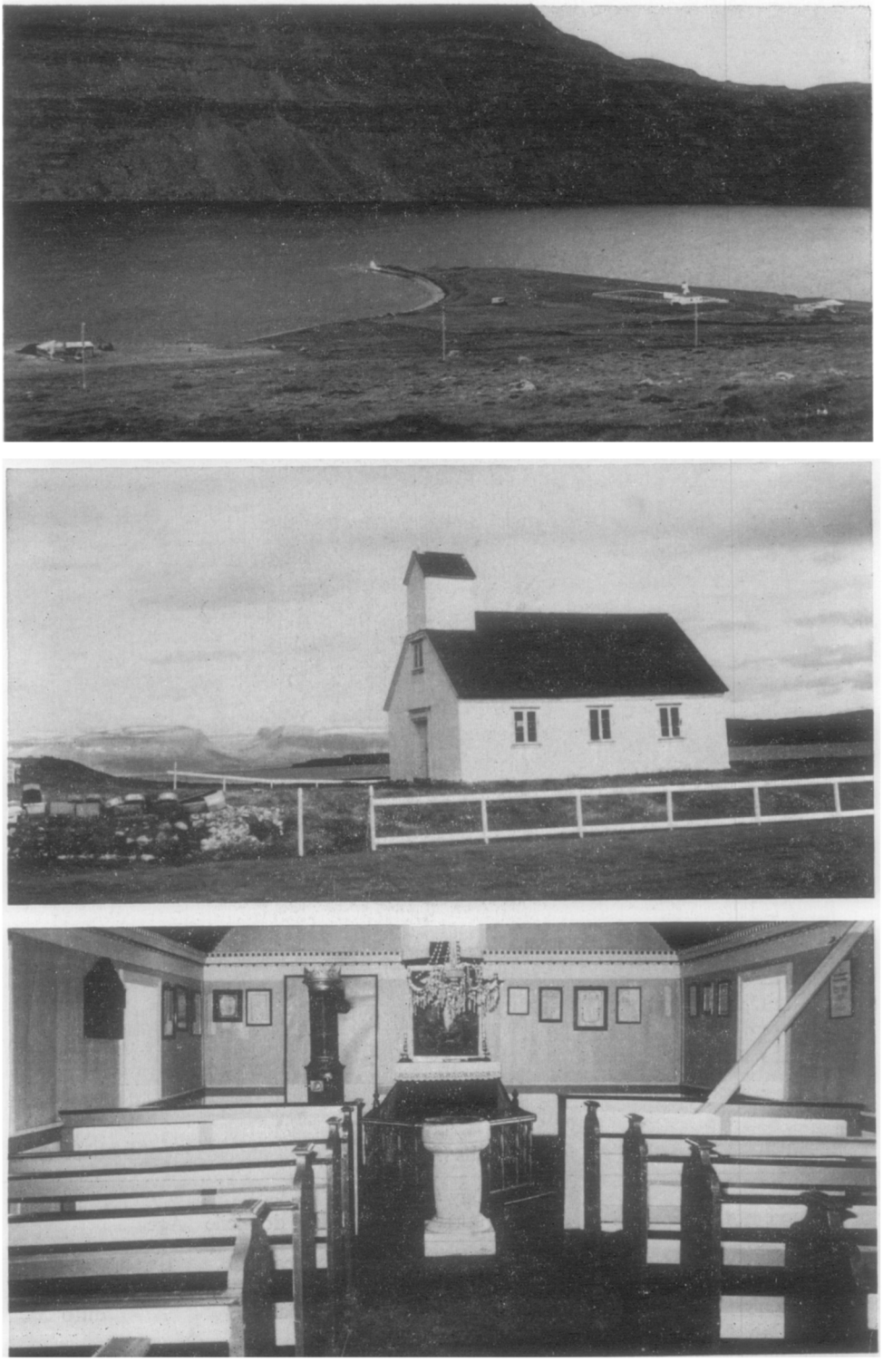


Figure 8. Eyri church, the location of the confirmation service of 21 May, 1904. (A) General view showing the church location on a spit within Seyðisfjörður. (B) The church looking across the main fjord, Ísafjarðardjúp. (C) Church interior. Source: Photos by authors, September 1981.

Figures A1–7 are referred to in the Appendix.

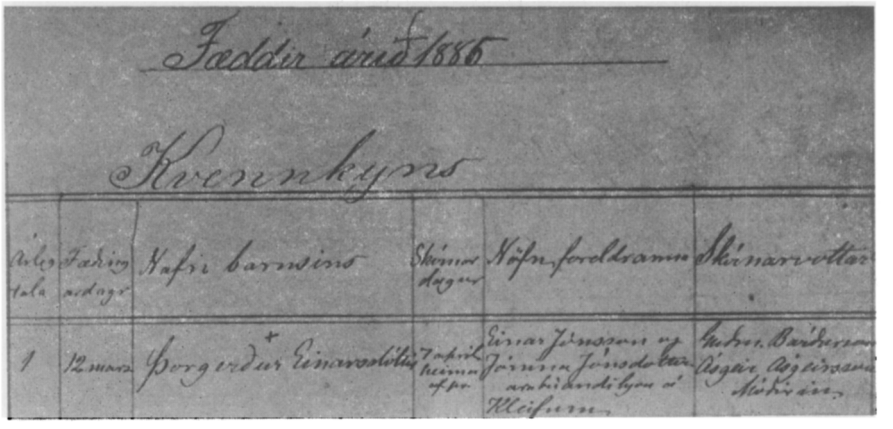


Figure A1. Entry from the church register showing birth entry for Þorgerður Einarsdóttir. Columns give (left to right) date of birth, name of child, where and when baptised, names of parents, godparents. Source: As Figure 4(B)–(D), p. 15.

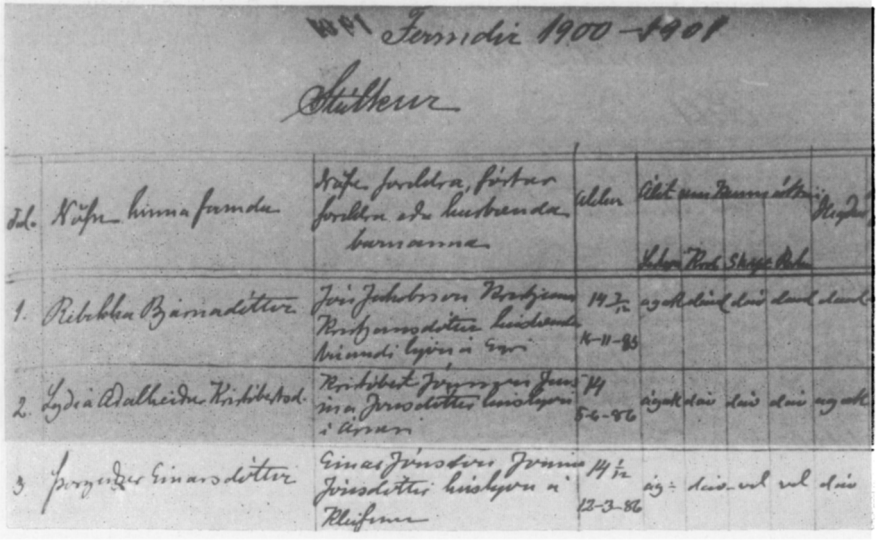


Figure A2. Entry from the church register showing confirmation entry for Þorgerður Einarsdóttir. Column headings as in Figure 6. Source: As Figure 4(B)–(D), p. 81.

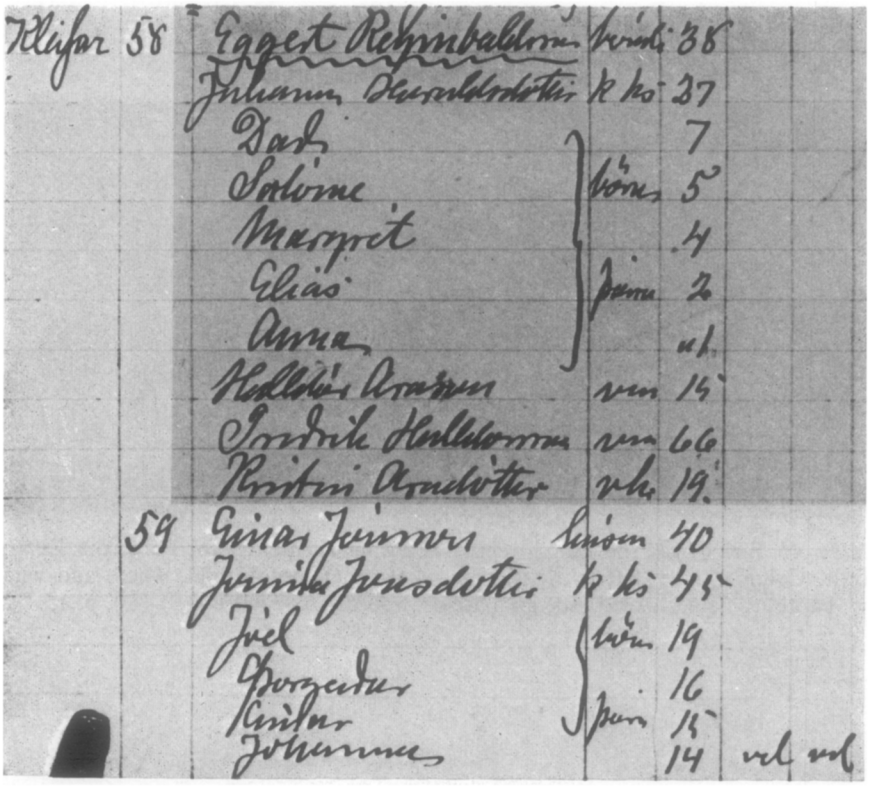


Figure A3. Extract from the parish census for Ögur and Eyri in Seyðisfjörður, 31 December, 1901, showing home of Einar Jónsson and his family at Kleifar. Source: As Figure 1.

Figure A4. Marriage entry for Þorgerður Einarsdóttir. Columns give (left to right) name, age and occupation of groom, name and age of bride, date and venue of wedding, best men. Source: As Figure 4(B)–(D), p. 102.

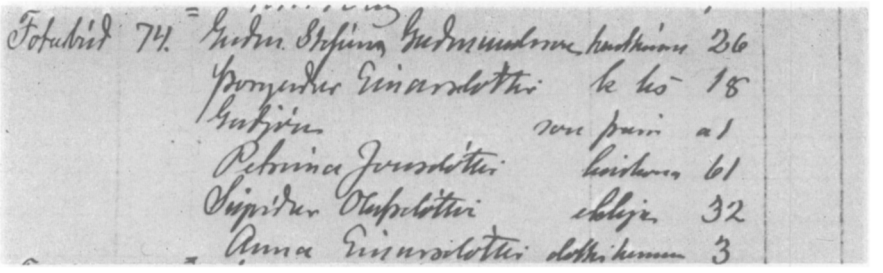


Figure A5. Extract from the parish census for Ögur and Eyri in Seyðisfjörður, 31 December, 1903, showing home of G. Guðmundsson and his family. Source: As Figure 1.

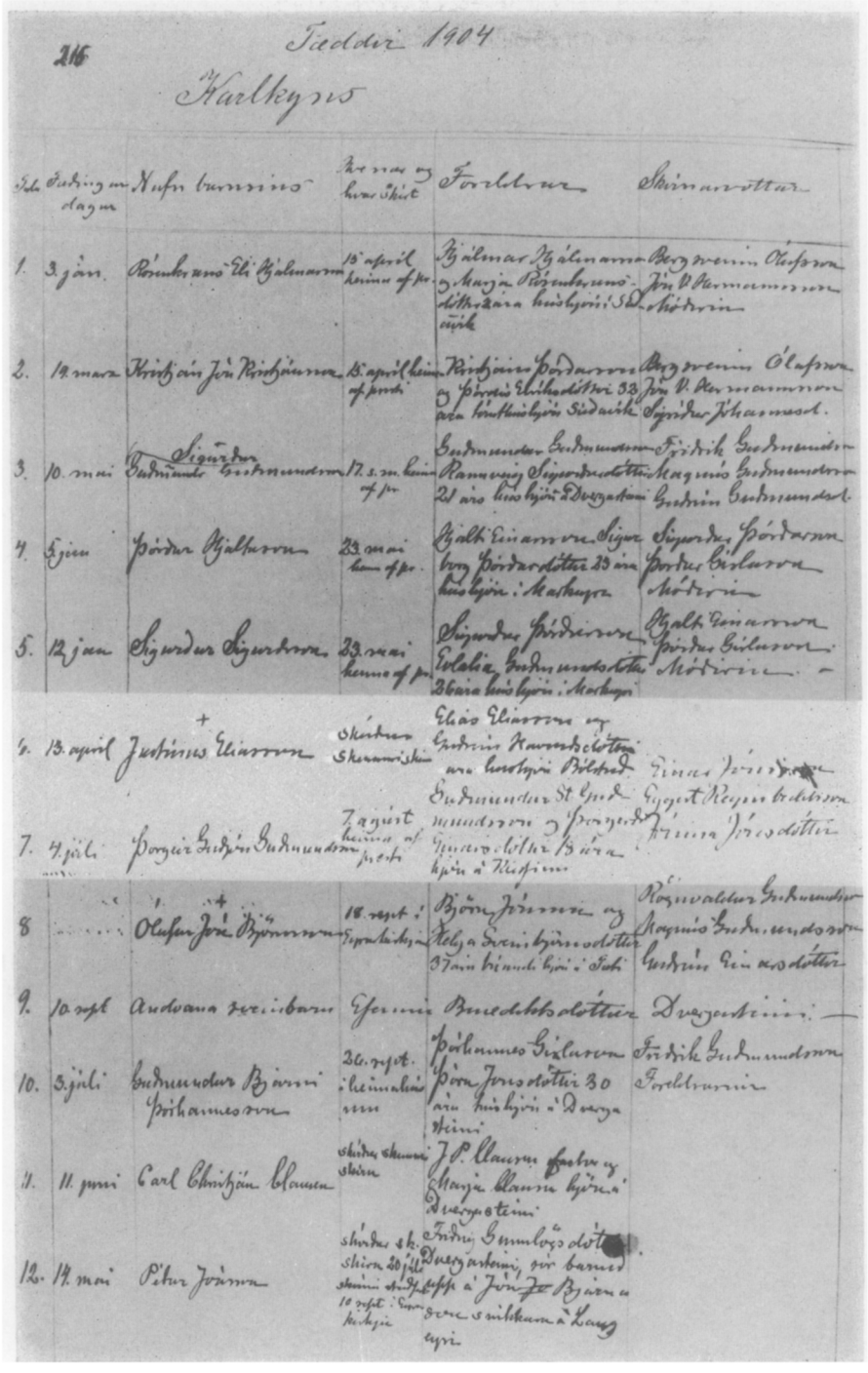


Figure A6. Extract from the church register showing birth entry for Þorgeir Guðjón Guðmundsson. Entry 6, Justinus, died from measles on 10 July, 1904 (cf. male entry 8, Figure 7). Column headings as Figure A1. Source: As Figure 4(B)–(D), p. 216.

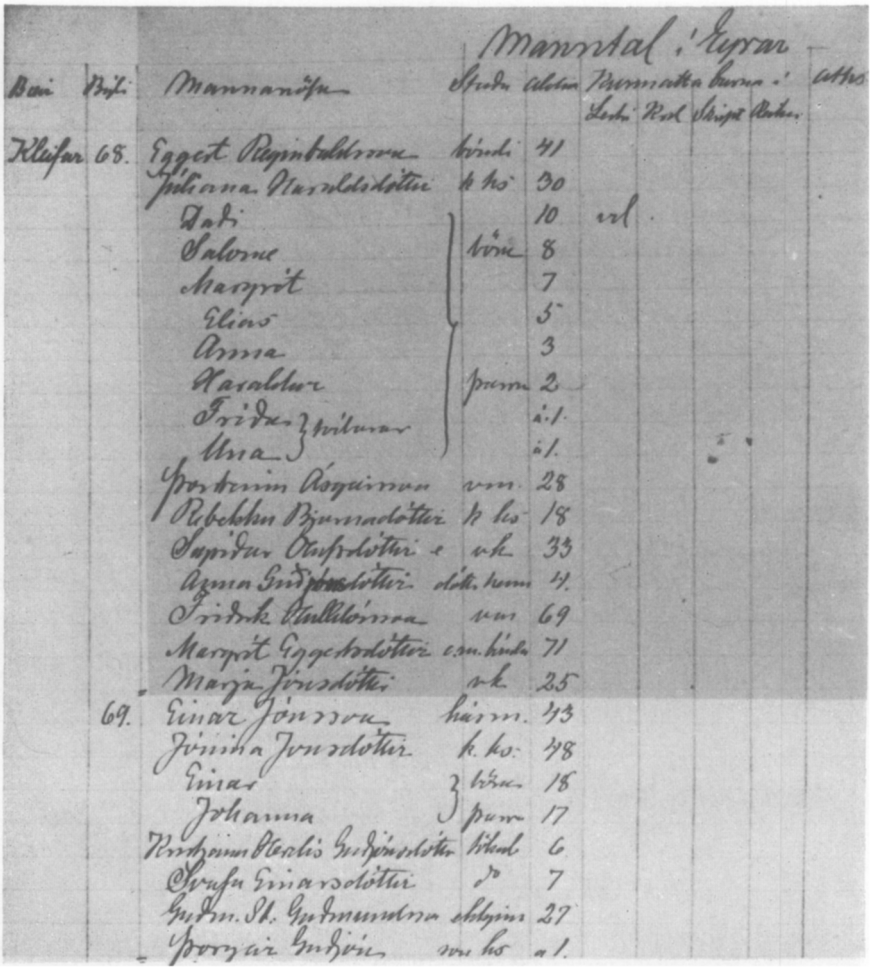


Figure A7. Extract from the parish census for Ögur and Eyri in Seyðisfjörður, 31 December, 1904, showing G. Guðmundsson living with his parents-in-law. Source: As Figure 1.

graphical area, the population at risk, and the disease being spread. In the second part, we use public health records to establish the way in which the disease diffused over the whole of northwest Iceland. In the third part, we focus on two critical parishes in the core area most severely affected by the epidemic and use a different set of sources (parish registers and newspaper accounts) to study spread at the local level. Finally, in the fourth part, we set the 1904 epidemic in a more general context and ask what we can learn from this type of reconstruction about spatial diffusion processes.

Background to the epidemic

Before looking at the spread of the epidemic as such, we need first to outline the geographical environment through which the diffusion wave was passing and the nature of the disease being transmitted.

The northwest peninsula of Iceland makes up about one-twelfth of the island's total area. It is distinctive in terms of its terrain, its settlement pattern, and its isolation.[1] As the map in Figure 1 illustrates, the area is characterized by long, narrow and sometimes branching fjords that penetrate deep into the peninsula. These break it up into more than fifty large fjords and embayments. The largest of these, Ísafjarðardjúp, is some 20 km wide and 80 km long and splits the peninsula into two parts. Each rises to a plateau with maximum elevations above 900 m; the more northerly has an ice cap, Drangajökull. The contrast between the barren, lake-dotted plateau and the fjords and valleys is very sharply defined with an abrupt transition sometimes forming a wall-like cliff.

The settlement pattern in 1904 reflected the spartan economy which had been evolved within the constraints of the rugged terrain and the sub-Arctic environment. Settlements were confined to (i) low-lying regions at the heads of fjords, (ii) spits extending out into the fjords, and (iii) coastal terraces. The airphoto in Figure 2 depicts a fragment of the fjord area shown in Figure 1 and illustrates the distinctive clustering of farmsteads in the three types of site. Confinement to such coastal locations was reinforced by the importance of fishing as a food source.

The isolation of the northwest peninsula of Iceland was both external and internal. It was not until 1950 that most fjord communities were connected to the rest of Iceland by a road system. In 1904 the only continuous links between communities were by sea; in the summer months, it was also possible to travel by horse across the plateau. At that time, the total population of less than 11,000 was spread around the long, indented coastline of an area roughly half the size of Wales. The external isolation was reinforced by the fact that the neck of land connecting the peninsula to the rest of Iceland is only 8 km across.

As regards the disease, measles is produced by a highly infectious virus that is spread directly from person to person without an intermediate host. Reasons for the selection of measles notifications from the group of infectious virus diseases for which data are available for diffusion studies have been stated at length by the authors elsewhere.[2] Here we may simply note four important attributes. First, the high infectivity yields a large number of notifications (250 a month for northwest Iceland during the period of the 1904 epidemic). Second, the transmission of the disease from person to person without the presence of an intermediate host allows demographic data to be used directly in any analysis. Third, person-to-person transmission of the disease also suggests that distance-decay factors are likely to operate in guiding the spatial pattern of outbreaks. Finally, measles has played a

central role in the development of quantitative epidemiological theory, and a number of the classic deterministic and stochastic models of epidemic spread were first derived from consideration of measles returns.[3]

Reconstruction at the regional scale

In a period of eight months, a major measles epidemic had been introduced into Iceland, reached its peak, and faded away. In this section, we look at the sources of information for tracing the history of this outbreak at a broad regional level, and the patterns which emerge from such an analysis.

In 1904, northwest Iceland had nine doctors to serve the needs of its 11,000 people. These were organized into seven medical districts and it was the medical officer for each district who provided the basic information from which an epidemic history can be reconstructed. Public health information in Iceland is recorded in *Heilbrigðisskýrslur* (*Public Health in Iceland*).[4] This first appeared in 1896 and information is presented in two forms:

(1) Details of the number of reported cases for a wide range of diseases, including measles, in each of some $n=50$ medical districts. From 1911–75 the data are published as a complete $n \times 12$ (months) matrix. Up to 1911 and since 1975, figures are given only annually by medical districts, rather than being temporally disaggregated. Prior to 1911, monthly case totals are also listed for Iceland as a whole.

(2) Written summaries are given of the course of each epidemic to have affected Iceland in a particular year. These are prepared by the chief medical officer for Iceland from annual reports filed in Reykjavík by the doctor in charge of public health in each medical district. The summaries contain details of the size and severity of the various epidemics. In addition, and crucially from a geographical point of view, many relate in some detail the spatial course of the epidemic through Iceland, giving the date of introduction of the disease into each district, its origin, and which farms and other communities were subsequently infected. In this paper, we have worked both with the published information (1) and (2), and with the manuscript reports[5] of individual doctors. The reports flesh out the bones of the published summaries; they enable us to construct the missing time-space data matrix for the measles epidemic of 1904.

The broad course of the epidemic is given in a succinct form in Table 1. Of the 1,993 cases, approximately forty per cent fell in the peak month of August and

TABLE 1

Monthly incidence of measles cases by medical district, northwest Iceland, 1904

District	Month J	F	M	A	M	J	J	A	S	O	N	D	Total
Dala								11					11
Hesteyrar				1			16	15	14	30	25		101
Ísafjarðar					9	54	226	c. 1200		19	2		1,510
Nauteyrar						12	62	40					114
Reykhóla						24	60	29					113
Stranda						1	29	51	19	9			109
Þingeyrar					5			22	8				35
Total				1	14	91	393	768	641	58	27		1,993

Note: The totals for August and September assume that the 1,200 cases in Isafjarðar are split equally between the two months.

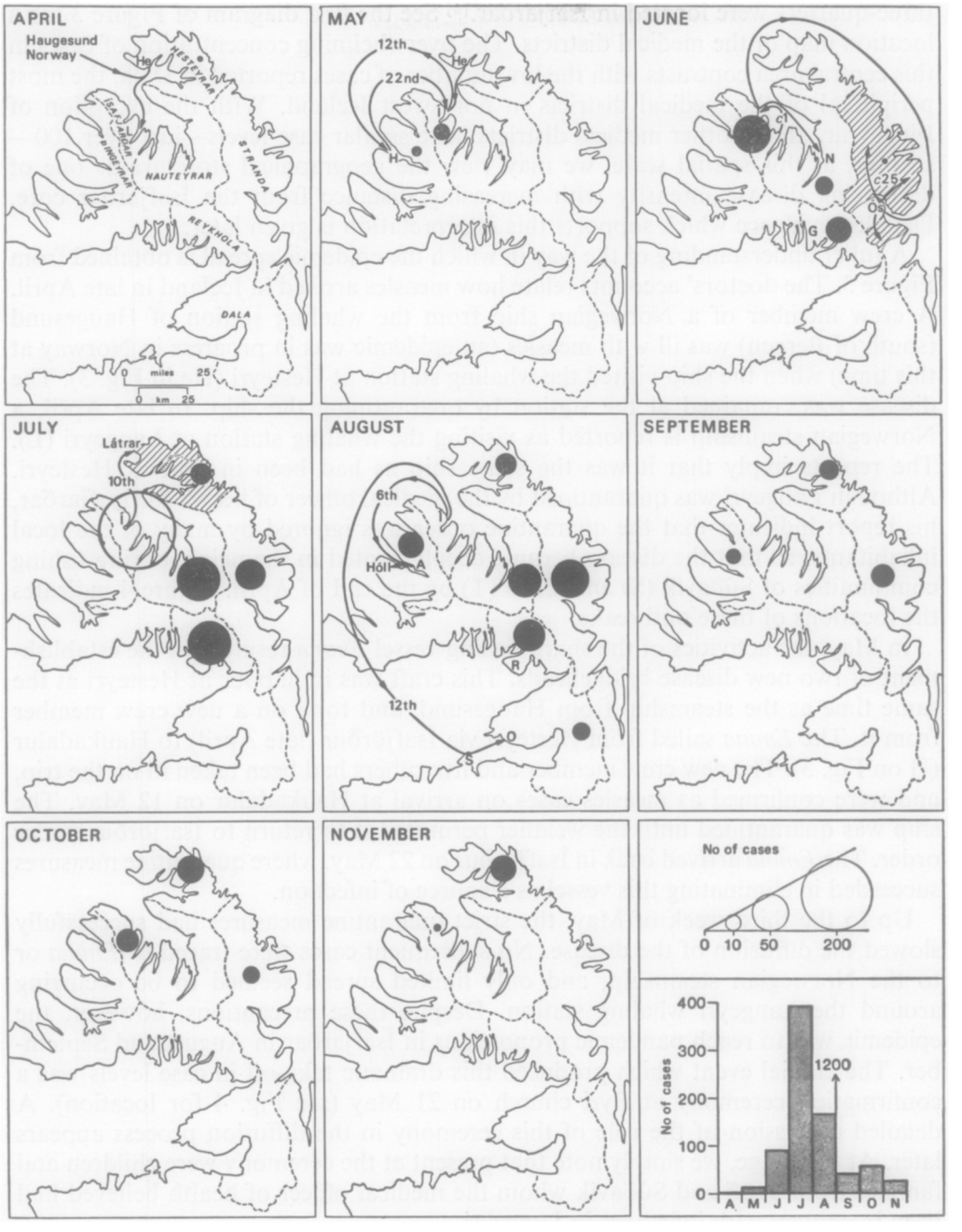


Figure 3. Spread of the 1904 measles epidemic in northwest Iceland. The number of reported cases in each of the seven medical districts is shown, together with the dates within each month on which the physician in each district recorded an index case moving into his area. In the histogram of monthly cases (lower right), the 1,200 refers to the estimated number of cases occurring in the Ísafjarðar pandemic of August and September for which precise dates are not known. These cases are not included on either the maps or in the histogram. Shaded areas denote regions infected by a single index case. *A*=Alviðruból, *G*=Gufudalur, *H*=Haukadalur, *He*=Hesteyri, *Í*=Ísafjörður, *L*=Langeyri, *N*=Nauteyri, *O*=Orrahóll, *S*=Stykkishólmur.

Data source: Annual reports of the medical officers of health for Dala, Hesteyrar, Ísafjarðar, Nauteyrar, Reykhóla, Stranda and Þingeyrar medical districts, 1904. Unpublished manuscripts in Þjóðskjalasafn Íslands (National Archives of Iceland), Reykjavík.

three-quarters were located in Ísafjarðar.[6] See the first diagram of Figure 3 for a location map of the medical districts. The overwhelming concentration of cases in this central area contrasts with the low number of cases reported in Dala, the most peripheral of the medical districts in northwest Iceland. With the exception of Þingeyrar, all the other medical districts have similar case levels—just over 100—so that, at this spatial scale, we may view the geographical structure as one of decreasing disease intensity with increasing distance from the Ísafjarðar core. Detailed evidence which supports this interpretation is given later.

A fuller understanding of the way in which the epidemic spread is obtained from Figure 3. The doctors' accounts relate how measles arrived in Iceland in late April. A crew member of a Norwegian ship from the whaling station of Haugesund (south of Bergen) was ill with measles (an epidemic was in progress in Norway at this time) when the ship visited the whaling station at Hesteyri (He in Fig. 3). The disease was contained at the station by quarantining the ship. In late April, a Norwegian steamship is reported as visiting the whaling station at Langeyri (L). The reports imply that it was the same ship as had been in port at Hesteyri. Although Langeyri was quarantined by the medical officer of health for Ísafjarðar, his report indicates that the quarantine order was ignored by many of the local inhabitants, so that the disease became deeply rooted in the neighbouring fishing communities of Súðavík (S) and Tröð (T) by the end of April. Figure 4 indicates the locations of these outbreaks.

In May, the activities of the shark-fishing vessel *Emma* resulted in the establishment of two new disease bridgeheads. This craft was in habour at Hesteyri at the same time as the steamship from Haugesund, and took on a new crew member from it. The *Emma* sailed from Hesteyri via Ísafjörður (late April) to Haukadalur (H on Fig. 3). The new crew member and five others had been taken ill on the trip, and were confirmed as measles cases on arrival at Haukadalur on 12 May. The ship was quarantined until the weather permitted it to return to Ísafjörður under order. The *Emma* arrived back in Ísafjörður on 22 May, where quarantine measures succeeded in eliminating this vessel as a source of infection.

Up to the third week of May, the strict quarantine measures had successfully slowed the diffusion of the disease. No subsequent cases were traced to *Emma* or to the Norwegian steamship, and only limited spread seemed to be occurring around the Langeyri whaling station. Despite these precautions, however, the epidemic was to reach pandemic proportions in Ísafjarðar in August and September. The crucial event which produced this dramatic take-off in case levels was a confirmation ceremony at Eyri church on 21 May (see Fig. 4 for location). A detailed discussion of the role of this ceremony in the diffusion process appears later. At this stage, we simply note that present at the ceremony were children and families from Tröð and Súðavík whom the medical officer of health believed had been in contact with infectives in Langeyri.

In June (Fig. 3), families whose members contracted measles as a result of the Eyri confirmation ceremony produced a multiplicity of contacts throughout the fjords in the southeastern half of Ísafjarðar. At this point, the medical officer of health abandoned all attempts to contain the spread of the disease in this rural part of the district: "The isolation of individual households in Álftafjörður [located in Fig. 4] would thus have been useless, and also journeys from and to Álftafjörður from various neighbourhoods here and there around the deep [Ísafjarðardjúp], were very frequent then".[7] The disease became established in the main town of the region, Ísafjörður, in the second week of June. On 7 June,

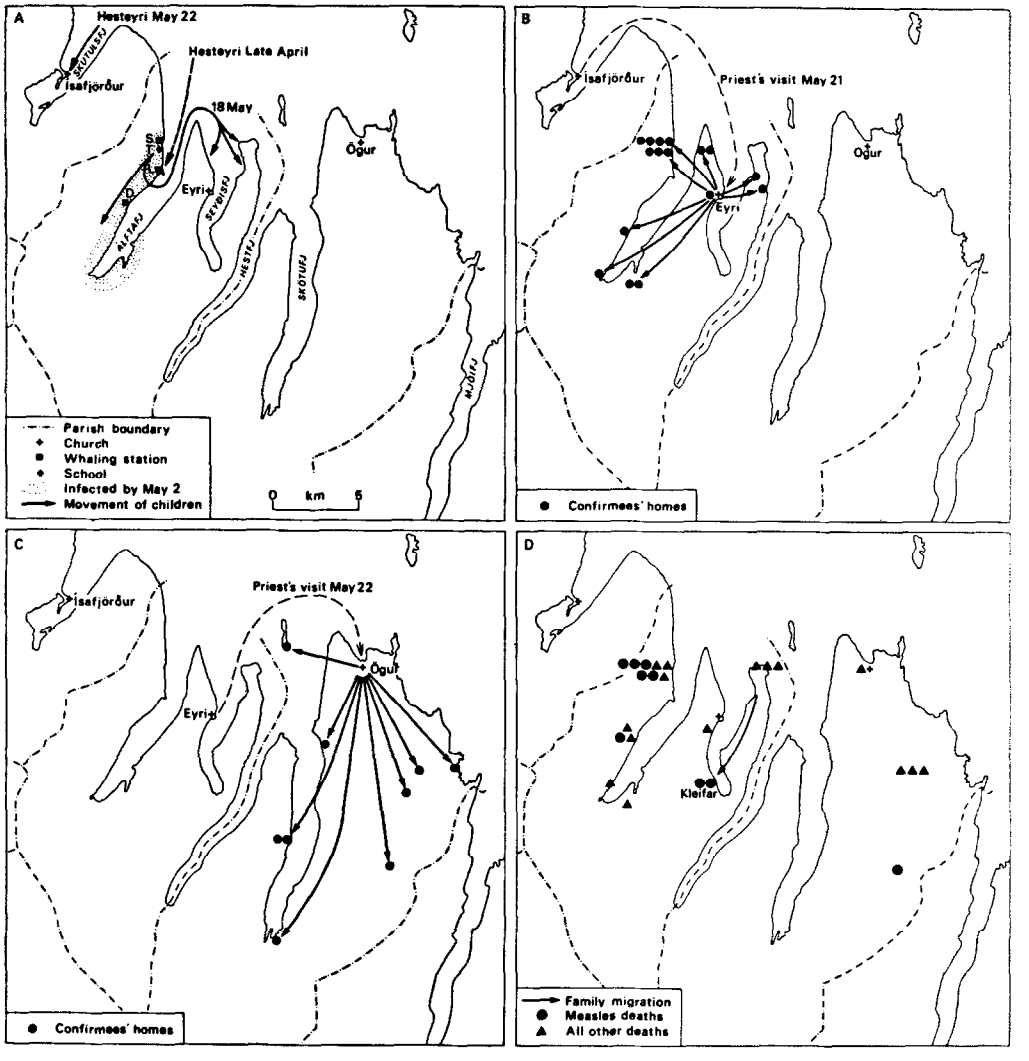


Figure 4. Spatial pattern of the 1904 measles epidemic in Eyri and Ögur parishes. (A) Initial spread into Álftafjörður in late April, Seyðisfjörður on 18 May, and Ísafjörður on 22 May. (B) Homes of children confirmed at service at Eyri church on 21 May (Whit Saturday). (C) Homes of children confirmed at service at Ögur church on 22 May (Whit Sunday). (D) Location of the homes of those dying from measles (June and July) and from all other causes during 1904. *D*=Dvergasteinn, *L*=Langeyri, *S*=Suðavík, *T*=Tröð.

Data source: (A) as Figure 3 for Ísafjarðar; (B)–(D) *Prestspjónustubók, 1904; Norður-Ísafjarðarprófastsdaemi, Ögur og Eyri í Seyðisfirði* (Church Register, 1904: North Ísafjörður Deanery, Ögur and Eyri in Seyðisfjörður) pp. 86–87, 162–163.

measles was diagnosed in a girl who had been at the confirmation ceremony at Eyri on 21 May. The medical officer of health comments:

> The same day, 7 June, I was called to a house here in Tanga [Tangagata, a street in Ísafjörður], and I found measles there too. There was an adolescent girl there, who had been confirmed at Eyri on Seyðisfjörður at Whitsun, but came from there to the town for domestic service, and then fell ill shortly afterwards. This house was immediately put in quarantine, even though it

was foreseeable that the town would not be saved, because communications with the house had been unchecked until this day.[8]

By the time the disease had run its course through the medical district and had died out in November, *every home in the district except one* experienced at least one case. The district had a population of 3,916 in 1911. In the epidemic, the health authorities recorded some 1,500 cases in the district and 23 deaths. They were so overwhelmed in August and September that detailed records were not kept for these months; the medical reports simply note "pandemia" and record 1,200 cases. Thus cases were being reported at the rate of 20 a day for two months and involved half the population of the district. Ísafjörður was to prove the source of infection for spread to many places in the northwest later in the year. In June, the disease was carried from Ísafjörður to Nauteyri (N in Fig. 3) and to Stranda. In the latter instance, a youth came to Ós for the summer. He fell ill with measles and the disease spread from this initial case to all the shaded areas of the district shown on the June map of Figure 3. In the same month an outbreak of unknown origin occurred at Gufudalur (G on Fig. 3).

On 10 July, the disease returned to Hesteyrar, carried there by a schoolboy returning home from Ísafjörður to Látrar. The epidemic rapidly took hold in the district, and by the time it had died out in November, all but seven homes in the district had been affected.

In August, the disease moved west and south. On 6 August, a crew member of the cutter *Fiskeren* carried measles from Ísafjörður to Alviðruból (A in Fig. 3) and subsequently to his home farm of Hóll. The whole fjord area was quarantined, and the infection was contained. The procedure of quarantining was similarly successful in Dala. The disease was brought to the area by a 25-year-old man who travelled there by boat from Ísafjörður to Stykkishólmur (S) and thence overland to Orrahóll (O in Fig. 3). Isolation orders restricted the spread to individuals on this one farm. The disease also appeared in Reykhóla in August. Although no source is given in the doctor's report, we must suspect some link either with the outbreak in contiguous Dala or with the pandemic in Ísafjörður.

The account we have given underlines several factors of prime importance in understanding the spatial diffusion of measles epidemics in Iceland. First, it highlights the role of single infected individuals (the index cases) whose spatial mobility played a crucial part in starting an outbreak in a given community. Fishermen and boat movements are of special interest in the Icelandic case. Once the index case arrived among a susceptible population, the high infectivity of measles ensured the rest. In excess of 90% of individuals at risk contract measles on first exposure (discussed on pp. 40–4 of the work cited in note 2). Secondly, it indicates the importance of communal activities which bring susceptibles together at a critical period; the confirmation ceremony at Eyri on 21 May will illustrate the point. Thirdly, we see the importance of school links in spreading the disease. Fourthly, it indicates the counter-measures taken to control the diffusion process by quarantining ships and farmsteads. Finally, we gain some idea of the upwards age bias in the occurrence of cases which emerges when there is a long gap since the last major epidemic (22 years in this instance). Many of the movements of index cases described above involve adults rather than children; most are seamen.

The doctors' accounts suggest that, at this spatial scale, we are dealing with a contagious spread process. While isolated cases occurred in several places from April to June, the main element in the history of the epidemic was the introduction

and the establishment of the disease in Ísafjarðar. From July to August, the diffusion process was dominated by the pandemic in Ísafjarðar. However, simultaneously, index cases carried the disease away from this core area to peripheral medical districts like Hesteyrar and Stranda where the epidemic finally expired in November.

Reconstruction at the local scale

Although the 1904 epidemic affected the whole of northwest Iceland, it was in the early hearth area around Ísafjörður that the fire had burnt most fiercely. Two parishes within that district promised to be of special value in tracing the local passage and impact of the disease, and are studied here. Again, we look first at the sources of evidence, secondly at what they show, and thirdly at the insights we can gain from them.

Demographic and morbidity information at a local level is available in the records of the Lutheran ministers. At the beginning of the twentieth century, ministers still took an annual census[9] in their parishes to complement their records[10] of births, christenings, confirmations, marriages, deaths (often including the cause) and in and out migration. Because the bulk of the population of Iceland at this period lived in named isolated farms rather than in urban areas, use of contemporary maps with the ministers' censuses permits the specific geographical location of most families to be established. These records form the basis of the micro-scale study described in this paper.

One important lead in the doctors' reports about the 1904 epidemic was the suggestion by the medical officer for Ísafjarðar that the event which led to the pandemic in the district was a confirmation ceremony on 21 May at Eyri church where suspected measles carriers were present: ". . . the spread of the disease was not out of hand until after Whitsun 22 May; that day [sic] there was a service at Eyri, children were confirmed, and a large number of people [were] at the church. After that the disease spread very fast".[11] For our good fortune, on Whit Sunday, 22 May, a similar confirmation service was held at the church in the contiguous parish of Ögur; on this occasion, no known measles carriers attended. We can therefore use information about events at Ögur as a control to assess the significance of the Eyri ceremony in the diffusion process.

Some idea of the character of the two parishes may be gained from referring back to Figures 1 and 2. On the air photograph (Figure 2) of Eyri parish, Langeyri and Eyri stand on dramatic spits reaching into the fjords. The only major settlement in Eyri parish, around Súðavík, is also clearly visible. As shown in Figure 1, the remaining settlement in the two parishes consists of groups of two or three habitations, each group forming a farming unit, scattered around the fjord edges. The sole inland penetration of settlement, in Ögur parish, is in a river valley. The absence of settlement in Hestfjörður is also marked, as is the tendency for the east-facing edges of the fjords to be more densely settled than the west-facing edges.

Figure 4 summarizes the main components in the diffusion process at this spatial scale. To prepare this diagram, various parish sources have been used in the way indicated in Figure 5. Figures 4B and C are obtained by following the route from entry I in Figure 5. Copies of the relevant pages in the confirmation register are reproduced in Figure 6. Figure 4D is obtained via the route from entry II in Figure 5. The pages from the register of deaths are reproduced in Figure 7. The basic spread pattern shown in Figure 4 is clear: sixteen confirmations in Eyri

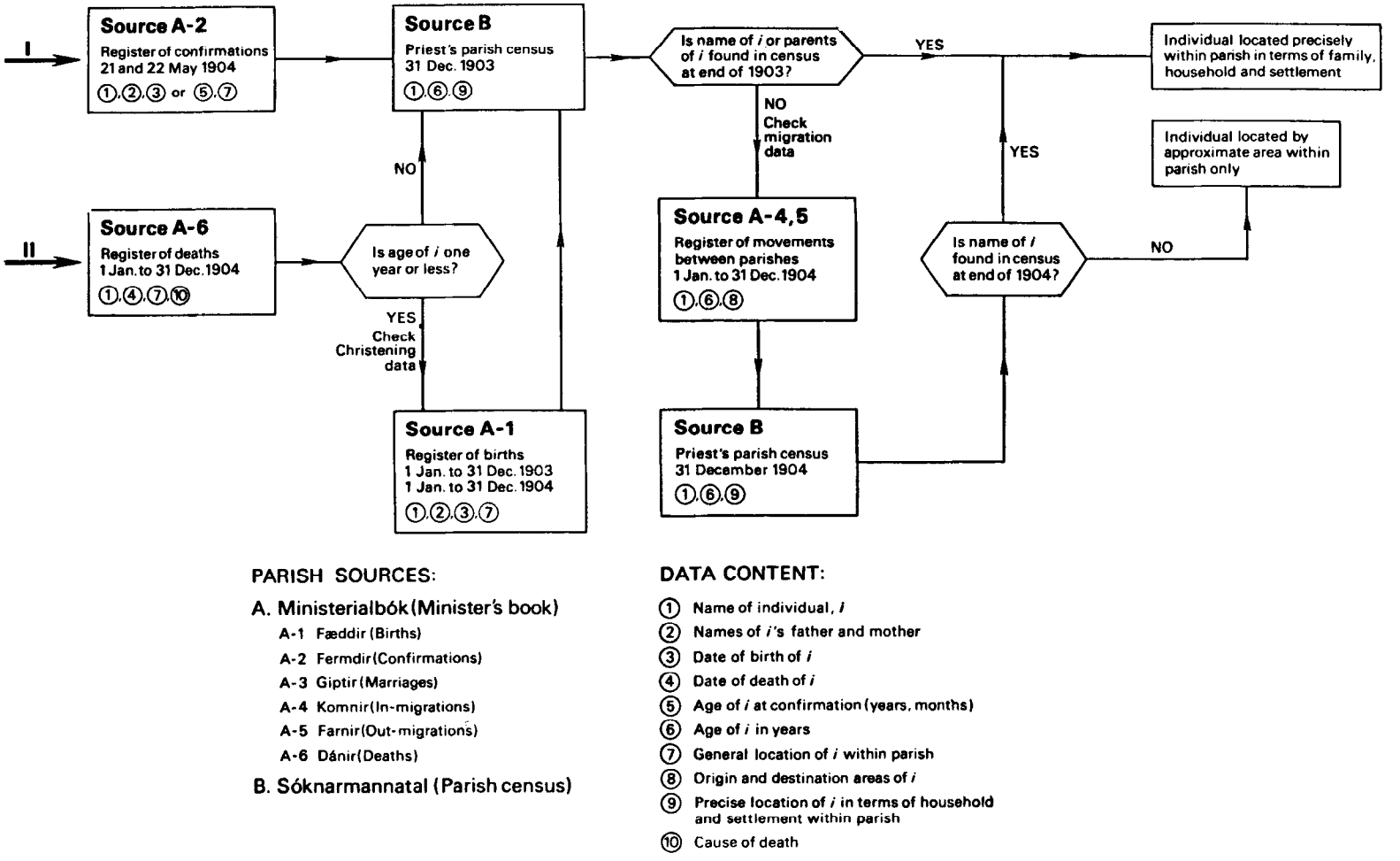


Figure 5. Flow chart showing the way in which the various parish sources were employed to locate individuals in the parishes of Eyri and Ögur. Route I is taken to fix the homes of confirmees and route II to fix the homes of those who died from measles. Photographs of various pages from the church register and parish census for Ögur and Eyri are included in the appendix to the paper where their use is illustrated in more detail.

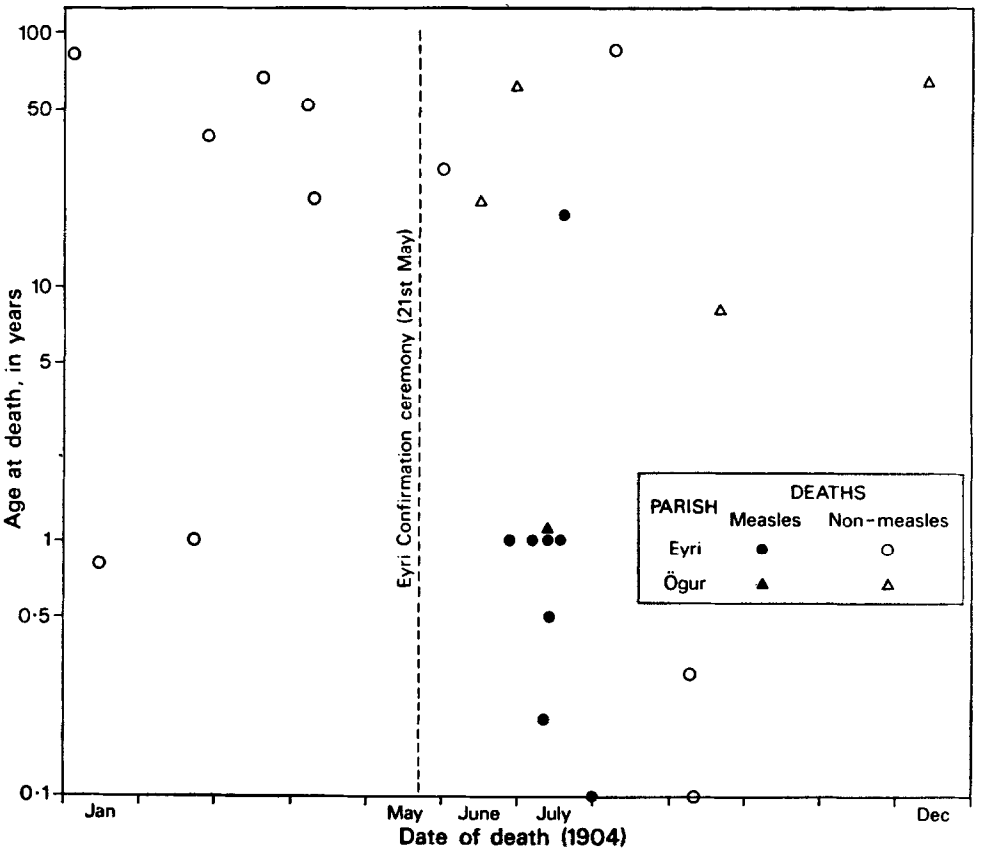


Figure 9. Temporal distribution of deaths in Eyri and Ögur parishes in 1904. The vertical axis of the graph is logarithmic, with 0·1 indicating deaths within 35 days of birth. Data source: As Figure 4(B)–(D), pp. 162–163.

resulted in eight traceable measles deaths, six in settlements close to the homes of confirmees (compare Figs 4B and 4D). In addition, the two measles deaths at Kleifar, which do not conform to this pattern, occurred in a family which had recently moved from the area at the mouth of Seyðisfjörður where Eyri confirmees lived (compare Figs 4B and 4D). Evidently, the intimate nature of the crowded church at Eyri (capacity about 80 people—see Fig. 8) provided ideal conditions for virus transmission. In Ögur, the corresponding figures were nine confirmations and one death.

Some idea of the impact of the epidemic on these small communities may be gained from Figure 9. In 1903, deaths in the two parishes totalled 18; in 1904 they totalled 24, of which, in a period of one month, nine were attributable to measles. In Figure 9, the concentration of measles deaths in July, the month before the pandemic in Ísafjörður, is striking, as is the mortality from measles in children under two.

The earliest of the measles deaths recorded was that of Auðunn Jónsson on 27 June (see male entry in Fig. 7). This was the only example of a death in the same household as one of the Eyri confirmees (his brother, Jóhannes Jónsson, male entry 5 in Fig. 6). Since the serial interval for measles is approximately two weeks, the gap of just over four weeks between the ceremony and the child's death suggests

that Auðunn was probably a first generation contact of the confirmee, who would have become infectious around 4 June. The majority of the measles deaths are concentrated in mid-July and probably represent second-generation cases following the confirmation ceremony. In one family, a child and his mother both died (male death 9 and female death 7 in Fig. 7).

The bias in the pattern of measles deaths in the direction of Eyri parish becomes even more obvious when the demographic structure of the two parishes is taken into account. The population of Eyri parish on 31 December 1903 was 604, and that of Ögur 319. The age distribution in each was, however, very similar (Fig. 10A) with, in both parishes, approximately 50% of the population aged 22 or under (that is, born since the last measles epidemic in 1882). Table 2 confirms the remarkable consistency in the demographic balance between the two parishes; about two-thirds of the total population of the parishes live in Eyri, and the proportion of under-22, under-5 and number of households are split in almost exactly the same proportion. The distribution of population among settlements, however, was somewhat different (Fig. 10B), with larger nucleations being more characteristic of Eyri. Using this information, Table 3 can be constructed. This gives the observed and expected (in brackets) division of measles and non-measles deaths between the parishes. Since only 36% of the combined under-22 population of the two parishes (or indeed the total and under-5 populations) is located in Ögur parish, we would expect, under the null hypothesis of no difference between the

Figure 10. Comparison of (A) the age distribution of the population and (B) the size of settlements in Eyri and Ögur parishes, 31 December, 1903. Data source: As Figure 1.

TABLE 2

Population characteristics of Eyri and Ögur parishes

	Eyri		Ögur		
	Number	Proportion	Number	Proportion	Totals
Total population	604	0·65	319	0·35	923
≤ 22	296	0·64	166	0·36	462
< 5	88	0·65	47	0·35	135
Total households	82	0·68	39	0·32	121
Average household size (persons)	7·37		8·18		

TABLE 3

Distribution of measles and non-measles deaths between Eyri and Ögur parishes

Deaths	Eyri	Ögur
Measles	8 (5·76)	1 (3·24)
Non-measles	10 (9·60)	5 (5·40)

Note: Observed values are unbracketed; bracketed are expectations based on population split between parishes.

two parishes, 36% of the measles and non-measles deaths also to have occurred in Ögur; conversely 64% ought to have occurred in Eyri. This argument yields the expectations shown in the table.

Let n denote the total number of measles (9) or non-measles (15) deaths observed in the two parishes, p be the expected proportion in the smaller parish (0·36), $q=1-p=0{\cdot}64$, and x be the number of deaths of a particular kind observed in the smaller parish (1 for measles, 5 for non-measles, deaths). Then, from the binomial distribution the probability of a distribution of deaths more extreme than that observed is

$$\text{prob}\ (x<k)=\sum_{i=0}^{k-1}\binom{n}{i}p^i q^{n-i},$$

where k is a selected constant.

Application of this formula to the measles deaths yields a probability of only 0·02 of a split between parishes which is more extreme than that observed; for non-measles deaths, the probability is 0·36. We conclude that the observed split is an extremely unlikely one for measles deaths, but not for non-measles deaths.

The spatial relationships between the susceptible population and the locations of measles deaths and confirmees' homes in the two parishes is summarized in Figure 11. The concentration of deaths and homes in the population centres on the western side of Álftafjörður (especially Súðavík and Tröð) is evident. Together, Figures 4 and 9 indicate that the contagious spread of the disease detected at the meso-scale is also present at the micro-scale. As we have noted, the first death from measles in the two parishes occurred in a household, one of whose members had been at the Eyri confirmation ceremony. The number of measles deaths is also biased in the direction of Eyri parish. This is commented upon by the medical officer of health for Ísafjarðar: "Most if not all of the deaths from

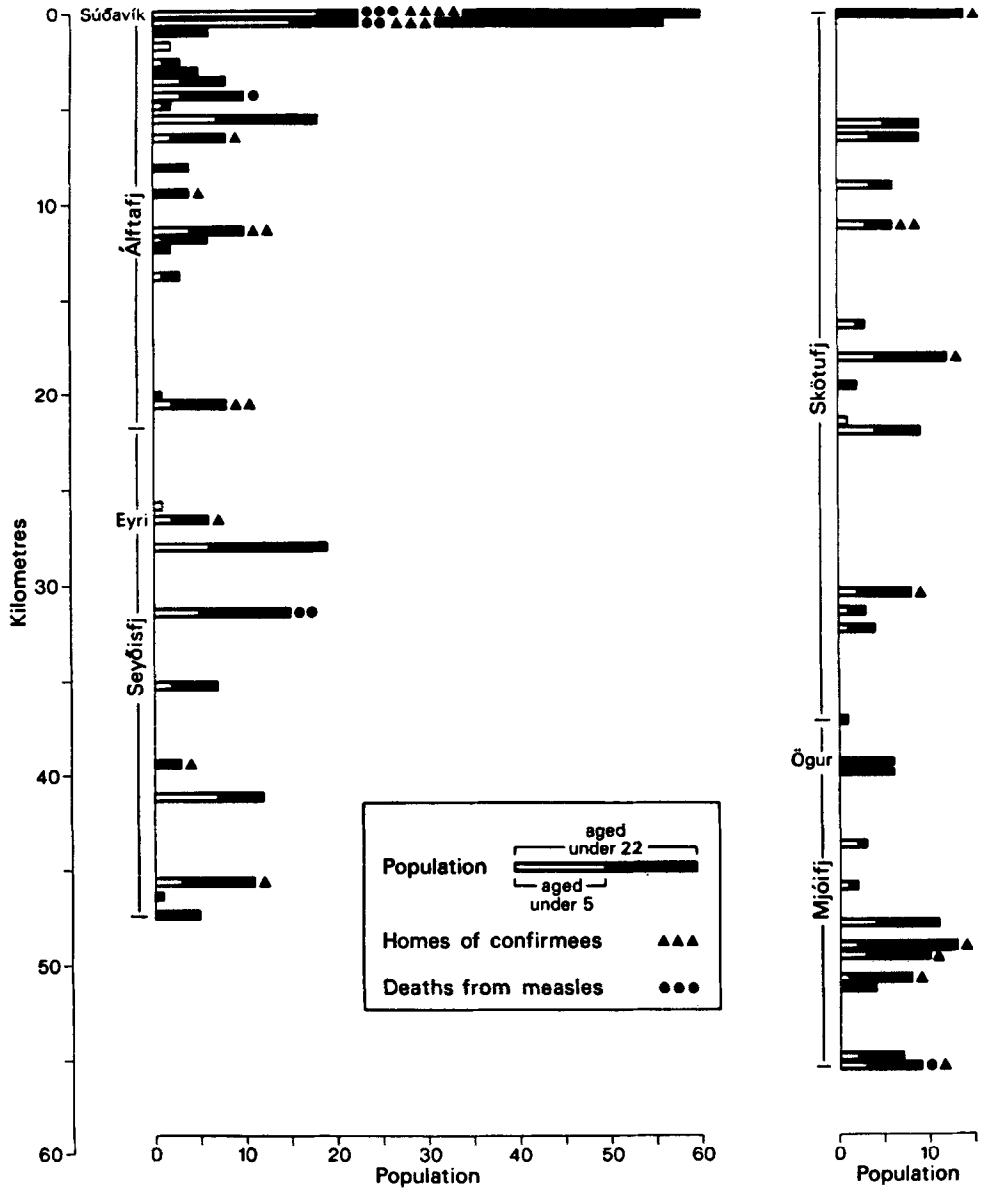


Figure 11. Relationships of the homes of confirmees to those in which deaths from measles occurred. Settlements are arranged by their location around the edges of the four fjords, with Eyri parish (Álftafjörður and Seyðisfjörður) on the left and Ögur parish (Skötufjörður and Mjóifjörður) on the right. Sizes of settlements are shown in terms of the main susceptible population; those under 22 represent individuals born since the last measles epidemic in the area in 1882, while the under-5 age group represents those particularly at risk. Data source: As Figure 1 and Figure 4(B)–(D), pp. 86–87, 162–163.

Ögurþing [the parishes of Ögur and Eyri in Seyðisfjörður] would . . . have been from Álfta- and Seyðisfjörður . . . Consequently it appears that proportionately more children would have died in Álftafjörður than elsewhere in the district."[12] Table 3 indicates that the non-measles deaths are, in contrast, split between the two parishes in almost the exact proportions we would expect from the population

distributions. In the analysis, the difference between the two parishes which we have not allowed for is the presence of measles carriers at the Eyri confirmation. The evidence therefore points to the fundamental role of this occasion in the localized dissemination of the disease.

The 1904 wave in a multiple-wave context

The measles epidemic of 1904 was only one of seventeen major waves which have struck Iceland in the hundred years since 1880. In this final section we place the epidemic in the broader context of the history and spread of such waves in terms of its intensity, its age of selectivity, and its locational restriction.

The 1904 epidemic is notable for its very high attack rate, particularly in the central area, and also for its moderate fatality rate (Table 4). The epidemic ranked fourth in terms of mortality rates, being exceeded by that of 1882 (1700 deaths or 23·6/000 population, case levels uncertain), 1907–8 (47·9 deaths/000 reported cases measles) and 1916–17 (23·9/000 reported cases measles). The mortality figures for 1882 imply that the attack rate in that epidemic must have exceeded that of 1904, but no other epidemic in the period produced higher *recorded* attack rates than the 1904 epidemic.

The epidemic is also unusual for the age distribution of cases. Measles is generally regarded as a childhood disease. In the nine post-1945 epidemics, the age distribution was: under-15, 85·3%, 15+, 14·7%. For the pre-war epidemics for which data are available, the following proportions hold: 1916–17, under-15, 64·6%, 15+, 35·4%; 1925–26, under-15, 76·2%, 15+, 23·8%. The corresponding figures of 58·3% and 41·7% for 1904 indicate an upward bias in the age distribution of cases for that epidemic. This may be accounted for by the long gap of 22 years between the 1882 and 1904 epidemics, compared with the average three-year gap between epidemics, 1904–74. As a result, a larger proportion of older individuals were susceptible.

Regionally, the 1904 epidemic was one of only two of the seventeen waves in the last hundred years to remain so strongly localized in one small part of Iceland. The sole comparable situation occurred in 1952–3 when a wave was confined to northeast Iceland. However, in that instance there were special circumstances; this region had been largely missed by the preceding island-wide wave and thus had a higher susceptible population level than the rest of Iceland. There is good reason to suppose that in the two decades intervening between the preceding wave of 1882 and 1904, the susceptible population had built up to a high level throughout Iceland.

The confinement of the 1904 wave to the northwest may well be due to four inter-related factors: first, the very isolated position of the region in relation to the rest of Iceland; second, the absence of rapid land communication which might allow easy community-to-community or region-to-region contact; third, the severity of the Ísafjörður outbreak and the press publicity[13] given to it alerted other communities to the danger of ships coming from northwestern parts; fourth, the main peak occurred in August at the end of the northern summer when contacts around the island were beginning to run down to their winter levels.

All the points mentioned so far in this section emphasize the distinctive character of the 1904 epidemic. However, one important general principle also emerges; like many person-to-person diffusion processes, contagious spread seems to have dominated at both the meso- and micro- scales. The paper has also illustrated the

TABLE 4

Morbidity characteristics of 1904 measles epidemic, northwest Iceland

District	Population (1911)	Total cases	Cases/000 Population	Deaths	Deaths/000 cases measles	Age distribution of cases 0–1	1–4	5–14	15+
Dala	2,055	11	5·4				2	6	3
Hesteyrar	706	101	143·1	2	19·8	8	20	29	44
Isafjarðar	3,916	1,510	385·6	23	15·2	10	64	86	150
Nauteyrar	927	114	123·0	2	17·5	5	22	46	41
Reykhóla	607	113	186·2	1	8·9	5	23	57	28
Stranda	1,468	109	74·3			2	23	29	55
Þingeyrar	1,372	35	25·5				10	15	10
Northwest Iceland	11,051	1,993	180·4	28	14·1	30 (3·8%)	164 (20·7%)	268 (33·8%)	331 (41·7%)

Note: No age breakdown of cases is available for Ísafjarðar in August and September. Source[1]

extraordinary richness of medical and parish records in Iceland as sources for the analysis of diffusion processes. Studies of the kind reported here indicate the main components of spread to be incorporated into models of diffusion processes and significantly enhance their value.

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Notes

[1] H. Preusser, *The landscapes of Iceland: types and regions* (The Hague 1976)
[2] A. D. Cliff, P. Haggett, J. K. Ord and G. R. Versey, *Spatial diffusion: An historical geography of epidemics in an island community* (Cambridge, England 1981)
[3] N. T. J. Bailey, *The mathematical theory of infectious diseases* (London 1975)
[4] This publication has appeared under the title *Heilbrigðisskýrslur* since 1911. The slightly more complicated titles of *Skýrslur um heilbrigði manna á Íslandi* (*Reports on public health in Iceland*) and *Skýrslur um heilsufar og heilbrigðismálefni á Íslandi* (*Reports on health and health matters in Iceland*) were used, 1896–1900, and 1901–1910 respectively. All are official government publications in Reykjavík
[5] Annual reports of the medical officers of health for Dala, Hesteyrar, Ísafjarðar, Nauteyrar, Reykhóla, Stranda and Þingeyrar medical districts, 1904. Unpublished manuscripts in Þjóðskjalasafn Íslands (National Archives of Iceland), Reykjavík
[6] Ísafjarðar is the name of the medical district, while Ísafjörður is the name of the main town in the district
[7] Unpublished annual report of the medical officer of health for Ísafjarðar, National Archives of Iceland, 3–4. See note 5
[8] *Ibid.* 4
[9] Sóknamannatal (Parish census). A full catalogue of all the parish censuses and church registers in Iceland is available as publication II of the National Archives of Iceland, *Prestsþjónustubækur og sóknamannatöl* (*Church registers and parish censuses*) (Reykjavík 1953)
[10] *Prestsþjónustubók* (Church register). See note 9
[11] Unpublished annual report of the medical officer of health for Isafjarðar, *op. cit.* 3
[12] *Ibid.* 7
[13] Two issues of the newspaper *Vestri*, published in Ísafjörður as volume III, numbers 38 and 39, on 25 and 30 July 1904 describe in detail the extent of the epidemic and the nature of the quarantine orders imposed. Copies of the papers are deposited with the medical officer of health's reports for Ísafjarðar, 1904

Appendix

This appendix contains sample pages from the parish censuses and church register for Ögur and Eyri in Seyðisfjörður. We illustrate how the records may be used to build up a picture of events by tracing the life of one girl, Þorgerður Einarsdóttir, who died from measles on 18 July 1904, at the age of nineteen. Þorgerður was born on 12 March 1886, the second child of Einar Jónsson and Jónina Jónsdóttir. Einar was a farmer and the family lived at Kleifar (Fig. A1). Þorgerður was confirmed in the Lutheran faith at Eyri church on 27 May 1900 (Fig. A2), and the parish census for 31 December 1901 (Fig. A3) records that the family were still living at Kleifar. On 23 October 1902, Þorgerður was married at Eyri church to Guðmundur Stefán Guðmundsson, a 25-year-old tenant farmer from Fótur (Fig. A4); the parish census for 31 December 1903 lists them as living at the farm (búð) at Fótur with one son, Guðjón, aged under one (Fig. A5). Þorgerður had become pregnant again in November 1903. On 4 July 1904, at the height of the measles epidemic in the area, she gave birth to a son, Þorgeir Guðjón Guðmundsson (male entry 7, Fig. A6). Measles is extremely dangerous for both mother and child if contracted when the mother is *in puerperum*. The doctor's report for Ísafjörður comments that this was unfortunately the case in this instance. The results were tragic. Þorgerður died from measles exactly two weeks after giving birth (female entry 7, Fig. 7 in main text)—compare the serial interval for measles. She was buried on 23 July. While her child survived, her first-born son, Guðjón, contracted the disease and died on 31 July. He was buried on 7 August (male entry 9, Fig. 7 in main text). Since the Lutheran minister was present for the committal, the infant child, Þorgeir Guðjón, was christened on the same day as his brother was buried (male entry 7, Fig. A6). His second name may well have been intended to commemorate his deceased brother. The parish census for 31 December 1904 records the father living as a widower with his infant son in his parents-in-law's home at Kleifar (Fig. A7). Since Þorgerður was recorded as dying at Kleifar, we may surmise with some certainty that she, her husband and child moved from Fótarbúð to her parents' home sometime in the first half of 1904, almost certainly for family support during her confinement. The migration is shown in Figure 4D of the main text. Thus was a family dismembered in the space of two weeks by one of the severest epidemics of measles to have affected Iceland in the last 100 years.