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TECHNICAL PROGRESS REPORT
OF
BIOLOGICAL RESEARCH ON
THE VOLCANIC ISLAND SURTSEY AND ENVIRONMENT
FOR THE YEAR 1973

Submitted to
Division of Biology and Medicine
U.S. Atomic Energy Commission
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The study involves the terrestrial biological research on the volcanic island, Surtsey, off the coast of Iceland, according to Contract No. AT(11-1)-3521.

Principal Investigator: Dr. Sturla Fridriksson
Reykjavik,
Iceland.

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Research dealing with the terrestrial biota on the volcanic island of Surtsey off the shore of Iceland and its environs has been financed by the U.S. Atomic Energy Commission.

According to the Research Proposal for the year 1973 the project involves a study of dispersal, colonization and ecological succession of terrestrial plants and animals on Surtsey and its environs.

The research work carried out during the summer of 1973 proceeded along the same general lines as that of previous summers with regular observations during the summer months. Two guards stayed permanently on the island during the summer and took care of the meteorological recording. Several students of biology made frequent trips to Surtsey and recorded biological events and collected samples.

In general the research in 1973 was carried out as follows:

MICROBIOLOGY

The following scientists have been connected with various fields of the microbiological study on Surtsey:

Professor Tomas D. Brock, Department of Microbiology, Indiana University, Bloomington, Indiana, U.S.A.

Professor Dr. Schwartz, Institut für Molekular Biologie, Biochemie und Biophysik, 3301 Stockheim, Germany,

who has been most interested in autotrophic bacteria of the soil.

Dr. G. H. Schwabe, Max-Planck Institut für Limnologie, 232 Plön, Germany, who has studied the microflora of the two main craters on Surtsey.

MOSSES AND LICHEN

Mosses have been studied by Mr. Bergthor Johannsson, M.Sc., of the Icelandic Institute of Natural History, Reykjavík, Iceland

The distribution of moss on Surtsey was recorded by biology students as well as some of the visitors. The lichen have been studied by Hördur Kristinsson, Akureyri, Iceland. The lichen flora of Heimaey was also investigated further in 1973.

VASCULAR PLANTS

The studies of vascular flora were performed by Sturla Fridriksson, Ph.D., Agricultural Research Institute, Reykjavík, as well as by biology students working as assistants.

Records were kept of seeds and other plant parts that drifted to Surtsey.

ENTOMOLOGY

The recording of insects found on Surtsey was continued during the summer of 1973 by the guards stationed on the island. The entomological work was

directed by Professor Carl H. Lindroth, Zoological Institute, University of Lund, Lund, Sweden. A book was published on this study, summing up the work in the last years.

VERTEBRATES

The ornithological studies were directed by Dr. Finnur Guðmundsson, Head of the Zoological Department, the Icelandic Institute of Natural History, Reykjavík.

The opportunity was used for investigating the role played by birds in the dispersal of living diaspores.

METEOROLOGY

The meteorological study was supervised by Hlynur Sigtryggsson, Director of the Icelandic Bureau of Meteorology, Reykjavík. Daily observations were carried out by the guards at the field station.

SOIL

Further investigation on the substrate were carried out. Such as the consolidation and palagonitization of the tephra which is being studied by Sveinn Jakobsson.

SCIENTIFIC BACKGROUND.

The bacteria and moulds.

From the records of diaspores washed upon the shores of Surtsey it may be understood that there already existed an organic source of energy on the island for various bacteria and moulds.

To these records may be added a long list of names of various foreign items of organic material, which had in the early existence of Surtsey drifted onto the shore or been carried to the island and could serve as an energy source for living organisms. The most effective contributors of such an organic matter were the thousands of seagulls which roost on the island and constantly fly around its shores. Some of the edges of the tephra hills were already in the first summer white with bird excrements. Another major energy source was a variety of debris washed up by the sea. This was mostly confined to the beach, especially to the high tide level, or a belt marked by the average tidal amplitude of 2.5 m. On the northern ness this belt has become increasingly broad. The ness may be completely inundated during high spring tides and is therefore littered with debris.

This organic matter is mainly in the form of seaweed and kelp or all sorts of driftwood, logs, tree stumps and boards, but also varieties of carcasses of birds, fish and

other marine animals. To this may be added strings and pieces of nets and all sorts of trash discarded from fishing boats in the surrounding waters.

All this material is a secondary source of energy in the ecosystem of Surtsey, which may be used by some of the local organisms and which will in a number of ways influence the development of life on the island.

During the summer of 1964 it could be noted that fragments of seaweed and carcasses were decaying at the high tide mark and were obviously being utilized by bacteria. These processes of breakdown were however not of special interest, and the microorganisms attacking these organic items would not differ markedly from those found elsewhere on any southern shore of Iceland.

The drifting of debris to the island continues, but there is no marked increase in organic deposit from one year to another. Some of the debris is undoubtedly buried in the sand, other is washed out again, and the carcasses on the shore are immediately cleaned up by the numerous seagulls that constantly search the shore for any kind of food.

The primary source of energy in the Surtsey ecosystem is sunlight, which can be utilized by the photosynthetic plants that are gradually colonizing the island, but no such plants were available during the first years of the islands existence.

On Surtsey energy was also available as electricity and as thermal energy from the volcanic activity or the energy produced by chemical reactions. Through the catalyses of such energy there might even have been formed some simple organic compounds of abiogenic origin. This primary energy source available for the first micro-organisms of the Surtsey ecosystem was of major interest for the study of the first steps in a biological succession, starting with the colonization of primitive micro-organisms on the inert substrate and ending with a highly developed climax community containing numerous lower and higher organisms.

Although the shores of Surtsey soon obtained scattered deposits of organic matter of foreign origin, the main part of the island was clean and devoid of these materials, and literally speaking completely sterile at the time of the formation of the island. The substrate was even repeatedly sterilized by the rain of volcanic ash from the eruption of the smaller islands that spread many layers of tephra over most of its original surface. But even a desolated island does not remain free of micro-organisms for any length of time.

The microflora invading Surtsey mainly disperse by ocean and by air. During stormy weather the waves may splash sea foam far upon the island and bring with it various marine micro-organisms. There they will encounter a new environment both regarding salinity and pH. This latter has been measured in the top layer of tephra to vary in the range from 4.2 to 6.5. Some of marine micro-organisms were capable of establishing on the Surtsey sub-

strate, especially in the ocean beach interface. When substrate from the beach was investigated, a number of bacteria and moulds were obtained.

The airborne microflora was measured on Surtsey on various occasions, and the quantity of organisms in the air was compared to that above cultivated and populated areas. These tests proved that there was a constant microbial dispersal by the air currents to the island, but the microflora of the air over Surtsey was scanty in species and low in number of individuals per volume compared with counts in the air of highly developed communities in the adjacent island of Heimaey and on the mainland of Iceland. It was noted that direction and velocity of wind affected the quantity of airborne organisms. During northerly winds soil dust was brought from the mainland, and at the same time air carried an increased number of organisms to the island. Most of the airborne micro-organisms were saprophytes, and no typical animal intestinal bacteria of the coliform group were found when different media were exposed to the air on petri-dishes.

Although micro-organisms were rather easily carried to Surtsey by air, by ocean or even by animals, they have not generally colonized the tephra substrate of the island. The surface of the tephra cones has repeatedly been sampled for such organisms, but although they are present on the surface in small numbers, this substrate was apparently not suitable for supporting micro-organisms because of rather high salinity, lack of organic matter and

of especially because of the low moisture content.

Despite the precipitation in the Surtsey area being quite high, no rain water accumulates in any amount on the island but seeps right through the porous substrates, whether it is of lava, tephra or sand. During droughts the surface consequently does not hold sufficient moisture to support the life of micro-organisms.

Where moisture is present, however, both algal and bacterial life has been able to establish. Many fumaroles that are still active provide, for example, moisture which condenses in surrounding crevasses. Microscopic examinations of such habitats have revealed a few bacteria per sample. In 1966 rod-shaped forms of very narrow bacteria $<1 \mu$ in diameter were, for example, detected growing on a rock in one such fumarole, and in 1970 a direct microscopic examination of the Surtsey substrate showed that bacteria were widely distributed throughout the terrestrial environment on the island. Roots and rhizoids of plants growing on Surtsey all had a high bacterial population. Such bacteria may have been brought to the island attached to the diaspores and are now growing on the organic material excreted by the higher plants.

Some of the habitats on Surtsey are quite unique in respect of diversity and extremes in temperature, such as the fumaroles and the hot areas, which have various gradients of temperature and moisture. There the bacteriologists have observed in small numbers both Thiobacilli thiooxidans and

ferrooxidans whereas denitrifying and nitrifying bacteria were more frequent, but so far tests for desulphurizers have given negative results.

The moulds which are found on roots of higher plants were very likely brought with the diaspores to the island, but mould spores are apparently also dispersing to Surtsey, and moulds have been found on enriched media, for example Penicillium citrinum and Phoma putaminum.

The algae.

The marine algae were pioneer colonizers of the pedestal of Surtsey and became abundant in the littoral region a few years after the formation of the island. In contrast to this the dryland of Surtsey has in general not been colonized by the terrestrial algal species. It has often been suggested that algae are the pioneer plants on a new substrata. This idea is partly based on the discoveries at the volcanic island of Krakatae, where the blue-green algae were found to be the early colonizers. This, however, has not been the case on Surtsey, and the algal mats which are now found in a few places on the island ten years after its formation are virtually all formed by the coccoid green algae (Chlorophyta).

Marine algae apparently disperse in great quantities by ocean and can colonize the new substrate within a short time. In contrast, the terrestrial algae do not withstand much salinity, and their dispersal to Surtsey mostly takes place by wind via the air.

It has also been demonstrated on Surtsey that birds carry algal spores and tissues on their feet, and it has even been suggested that insects play a minor part in dispersal of algae.

The transport of terrestrial algae is, however, more restricted than is the dispersal of marine algae via the ocean route. Thus air transport, for example, seems to be selective towards species with small size organisms. This difference in means of dispersal and therefore also in the quantity of capable colo-

nizers is, however, not a sufficient cause to explain the slow rate of colonization of the terrestrial algae on the dryland of Surtsey, compared to the rapid development of societies of marine algae on the socle of the island.

The variation in the algae population in these two biomes is rather due to a difference in their environmental conditions. Thus, the substratum below sea-level mainly serves as a mechanical support for the organisms, the nutritive matter being available in the salt water, while the terrestrial algae are dependent on nutrition from the dryland substratum. Similarly, the toxic effect of the volcanic salts has been readily washed out of the substrata below sea-level, but may be detrimental to algae in the dryland biome. The erosive effect of the tephra blown back and forth by the wind may be more harmful than similar abrasive effect of tephra which is washed by the waves. The greatest difference in the environment of these two biomes, however, remains in the availability of water. In the terrestrial habitats the substrate, whether it is the solid lava or the loose tephra, is often low in moisture. This periodical lack of water in the superficial substrata of the dryland is apparently the greatest hindrance to the algal establishment, while there is obviously no such water shortage below sea-level.

While various algae are thus rather readily dispersed to Surtsey, they are in general not able to establish or to become dominant plants in the dryland communities.

Compared with the numerous bacteria which have been recorded in the air or on the cinder surface, a wide variety of blue-green algae have been collected on Surtsey and isolated by enrichment culture techniques.

The accumulation of these airborne algae is apparently most abundant at the base of the cinder cones, as they may be washed down with rain and carried to lower levels with the run off water. Thus the greatest amount of blue-green algal species have been recorded at the base of the southern slope of the tephra cones. Altogether over 100 species were recorded in 1968, and over 160 species have so far after ten years been identified growing on artificially enriched media from samples collected at these sites. Although the abundance of species may be greatest at this base of the cinder cone and in the sheltered places around the craters, airborne algae capable of surviving have been collected in various surface samples from all over the island, but these are simply not able to establish on the island.

There exist, however, some stable algal settlements on Surtsey, and in a few places layers of algae may be observed. These are, for example, areas on both lava and tephra, where roosting birds have supplied fertilizer to the substrate. The colonies at these sites consist almost exclusively of coccoid green algae (Chlorophyta).

Some algae have also been able to establish where moisture levels are high in crevices of lava, or where steam condenses from fumaroles. On the edges of some such fumaroles the ash particles gradually stabilise, forming a compact, moist crust on which colonies of algae could establish. In 1968 eight species of blue-green algae were recorded in the area of the two central craters, as well as 100 other algal species including 74 Diatoms. These were either discovered together or in association with bacteria and mosses, the largest colony being 30 sq cm in area. This development continued in the following years, and the number of species in the small oasis around the fumaroles increased. These algal settlements, however, have not become conspicuous, and the blue-green algae are quite unimportant as primary colonizers of Surtsey. One exception to this was a wet spot around a bucket filled with rain-water placed on the lava as a trap to attract birds. In this artificial habitat, which received a large amount of bird droppings, a mat of blue-green algae had been formed in 1972, occupied by Oscillatoria.

These primary colonizers on Surtsey, however, do not all have to rely on organic supply of nitrogen. Another species of blue-green algae found on the island is Anabaena variabilis. This was first discovered in 1968. The following year three Nostoc species were also among the algae recorded. These species have the ability of fixing molecular nitrogen. The nitrogen fixation is, however, rather low under the

Surtsey conditions compared with warmer habitats, and the nitrogen fixation of these algae can not be considered of major ecological importance in the development of life on Surtsey.

The algal species represented in the microflora of Surtsey are largely identical with the flora of Icelandic soils. The colonists on Surtsey, however, seem to be of species that are of rather small size or are easily transported by spore forms. Although the algae are not necessarily pioneers in the substrate, they are often found in close relationship with the first colonisers of higher plants and are generally represented at the locations occupied by moss.

In the high-temperature areas surrounding steam vents near the old Surtur crater, some of the blue-green algae form a faint green colour. This area is occupied by the thermophilic species Mastigocladus laminosus, which grows at temperatures in the range between 57° to 64°C and in hot springs of alkaline to neutral pH. This thermophilic species is a cosmopolitan blue-green algae, which is common in the hot springs on the mainland of Iceland, those closest to Surtsey being at a distance of 75 km. The inoculum which was transported to Surtsey may have dispersed by air or by birds from these sources. But if precautions are not taken, scientists working in thermal areas may also become agents of dispersal.

The lichens

It is a widely current belief that lichens are pioneer forms of life in the colonization of new rocky substrata. This is also a fact in respect of many new lava flows throughout the Icelandic mainland, especially those occurring at high altitudes.

It was thus expected that lichen would be an early colonizer of the Surtsey lava. The substrate was therefore thoroughly studied every year following the formation of the island, and bird feet were investigated ^{to see} if they could serve as means of transport for possible lichen colonists.

It was surprisingly not until the summer of 1970 that the first lichen were found on Surtsey. At that time two communities of lichen were, however, observed in the vicinity of the Surtur II crater. At both sites the habitats received moisture and warm air from a thermal area.

One of these habitats was on a lava crust north-east of the crater. It was occupied by small specimens of Stereocaulon vevuvianum the common pioneer lichen of the Icelandic lava flows.

The other habitat was situated on the outer side of the north slope of the crater. This was occupied by two species, Trapelia coarctata and Placopsia geliga. This community was also better developed than the former and covered a strip of several meters in length. T. coarctata has not previously been recorded

in Iceland but may well be present on the mainland. It is a crustose lichen that was so abundant on the site at Surtsey that it gave the surface of the rock a pale yellowish-brown colour. P. gelida was represented by fewer individuals, but this is a common species on postglacial lava flows in Iceland, so it may be expected that both this species and S. vesuvianum will spread out in the Surtsey ecosystem.

The mosses

It was not until the middle of August 1967 that the first moss colonies were discovered on Surtsey. These were found on a sand-bank at the northern edge of the New Lagoon. The plants were all of the same species, Funaria hygrometrica, and in an early stage of growth. A month later, the second location of mosses was observed at the edge of the central lava crater, where the colonies consisted of two species; Funaria hygrometrica and Bryum argenteum.

These two moss species, the first to colonize the substrate on Surtsey, are common on the mainland of Iceland. The plants apparently grew from spores that had dispersed to the island by wind, and, in the case of the communities at the lava crater, the colonization became permanent and formed a centre for further establishment of mosses on the Surtsey lava.

In the following summer three new moss species were found in addition to the already existing moss population on the island. These were Leptobryum piriforme, Pohlia bulbifera and Ceratodon purpurens.

In 1969 the moss vegetation on the Surtsey lava became more conspicuous with plants occupying the lava in hollows and caverns, where sand had been deposited, and some even settling on the bare lava. The moss was, however, most vigorous where there was heat and steam emission from fumaroles, and where the vapour stabilized the sand and kept a constant moisture in the substrate.

In 1970 the number of moss species on Surtsey had increased to 16, and their distribution had extended into the southern part of the lava apron. The species F. hygrometrica and Racomitrium canescens were largely responsible for this distribution.

The following year 20 new species of mosses were recorded on the island with the total distribution gradually extending over the lava flow.

The spread of growth was then mainly towards the west but was hindered on the northern side by the tephra hills. Apparently the tephra was not a suitable habitat for any of the moss species. Racomitrium canescens was the dominant species.

However, it did not form a heavy cover - only small tufts here and there. In the years 1972 and 1973 the moss cover on Surtsey's lava developed further, but increases in distribution slowed down as compared with its rapid development in previous years, as the most favourable habitats had already been invaded.

Other parts of the lava, which have not yet been colonized by mosses, are rather hostile habitats for these plants; some too close to the splashing zone, others too sandy and erosive.

The species and their distribution.

On the vegetatin maps (Fig. 2-10) the gradual development in total distribution may be noted. When the distribution maps from 1971 and 1972 are compared, it seems there has been a retreat of the moss cover on the southeastern part of the island. This may be due to the fact that in this region the shore has been broken down by the waves during winter storms and the sandy beach washed away, the salt spray from the ocean thus being more effective than in previous years. In comparing the distribution maps with the substrate map, it may be seen that the maximum distribution, which the moss population has reached, in 1971 mainly coincides with the lava surface of the island.

In drawing the distribution maps, it was decided to use the 100x100 m quadrat mesh already used for other studies on the island. The distribution of a species within a quadrat was thus a unit in the total survey.

Since 1967 the moss species have gradually been invading Surtsey and colonizing the lava habitats of the island.

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

During our study of the moss population some species have been recorded in one summer and not rediscovered the following year, due to their scarcity in the vegetation. This, however, does not mean that the species could not have been growing continuously on the island since their first appearance. In other cases a new species has increased so rapidly that its colonization has been apparent every year. In Table 1 are listed the moss species discovered since moss first appeared on Surtsey. The species of moss so far recorded on Surtsey are 69 altogether of which 63 were known to be present in 1972. The greatest increase of species occurred in 1972, when 32 new species were discovered, including three new species of liverworts of the Jungermanniales group. In the moss flora of the island only some of the species listed are common, others are less common, rare, or very rare. In Table 2 the species have been grouped according to four categories, based on their abundance in the various quadrats and classified in the following manner:

- 1) Common species:
Found in more than twenty-five quadrats.
- 2) Rather common species:
Found in six to twenty-five quadrats.
- 3) Rare species:
Found in two to five quadrats.
- 4) Very rare species:
Found only in one quadrat.

Table 1
MOSS
LIST OF SPECIES FOUND ON SURTSEY
IN THE YEARS 1967 - 1972.

	'67	'68	'69	'70	'71	'72
Polytrichales:						
<i>Atrichum punctatum</i> (Hedw.) Beauv.						
<i>Psilopogon brevifolius</i> (Wahlenb.) Lindb.						
<i>Pogonatum purpureum</i> (Hedw.) Beauv.						
<i>Polytrichum commune</i> Hedw.						
<i>Polytrichum longisetum</i> Brid.						
<i>Polytrichum piliferum</i> Hedw.						
<i>Polytrichum squarrosum</i> (Besch.) Groth.						
Fissidentales:						
<i>Fissidens adianthoides</i> Hedw.						
Dicranales:						
<i>Ditrichum cylindricum</i> (Hedw.) Grout						
<i>Ditrichum heteromallum</i> (Hedw.) Britt.						
<i>Ceratodon purpureus</i> (Hedw.) Brid.						
<i>Distichium capillaceum</i> (Hedw.) B.S.G.						
<i>Aongstroemia longipes</i> (Sommerf.) B.S.G.						
<i>Dicranella crispa</i> (Hedw.) Schimp.						
<i>Dicranella heteromalla</i> (Hedw.) Schimp.						
<i>Dicranella schreberiana</i> (Hedw.) Schimp.						
<i>Dicranella subulata</i> (Hedw.) Schimp.						
<i>Dicranella varia</i> (Hedw.) Schimp.						
<i>Amphidium lapponicum</i> (Hedw.) Schimp.						
<i>Dicnodontium pellucidum</i> (Hedw.) Schimp.						
<i>Dicranopsis crispula</i> (Hedw.) Lindb.						
<i>Onchophorus virens</i> (Hedw.) Brid.						
Pottiales:						
<i>Encalypta</i> sp.						
<i>Encalypta ciliata</i> Hedw.						
<i>Trichotomum brachydontium</i> Bruck.						
<i>Barbula vinealis</i> var. <i>cylindrica</i>						
<i>Barbula fallax</i> Hedw.						
<i>Barbula ichmaconhila</i> C.Muell.						
<i>Barbula recurvirostra</i> (Hedw.) Div.						
<i>Barbula unguiculata</i> Hedw.						

Grimmiales:

- Grimmia apocynifolia (L.) Hedw.
 Grimmia confinis (L.) Hedw.
 Grimmia laevigata (L.) Hedw.
 Grimmia repens (L.) Hedw.
 Neogrimmia confinis (Hedw.) Loeb.
 Neogrimmia heterotricha (L.) Loeb.
 Neogrimmia longicauda (Hedw.) Loeb.

Furcrales:

- Furcra hyalomorphica Hedw.

Bryales:

- Pohlia annotina (Hedw.) Loeske
 Pohlia cruda (Hedw.) Lindb.
 Pohlia prolifera Kindb.
 Pohlia wahlenbergii (Web & Mohr.) Andr.
 Anomobryum filiforme (Dicks.) Hust.
 Leptobryum pyriforme (Hedw.) Wils.
 Bryum sp.
 Bryum angustarete Kindb.
 Bryum arcticum (R.Br.) B.S.G.
 Bryum argenteum Hedw.
 Bryum calophyllum R.Br.
 Bryum stenotrichum
 Bryum pallens Sw.
 Mnium hornum Hedw.
 Plagiomnium cuspidatum (Hedw.) Kop.
 Aulacomnium palustre (Hedw.) Schwaegr.
 Pell. notis sp.
 Pell. notis sp.
 Tetraodon hypoleuca sp.

Hypnales:

- Droopobolus (L.) (Hedw.) (Hedw.)
 Droopobolus (L.) (Hedw.) (Hedw.)
 Calliergon stramineum (Brid.) Hedw.
 Campylium polytrichum (B.S.G.) O.Jen.
 Amblystegium serpens (Hedw.) B.S.G.
 Brachythecium albicans (Hedw.) B.S.G.
 Brachythecium rivulare B.S.G.

'67 '68 '69 '70 '71 '72

Brachythecium salebrosum(Web & Mohr.BSG.

Hypnum lindbergii Mitt.

Rhytidiadelphus squarrosus(Hedw.)Warnst.

Isopterygium pulchellum(Hedw.)Jaeg & Sauerb.

Marchantiales:

Marchantia polymorpha L.

Jugentanniales:

Cephaloziaella

Scapania sp.

Solenostoma sp.

Table 2

^{moss}
A list of species ~~from 1972~~ growing on Surtsey in 1972, grouped according to the four frequency categories:

1. Common species: (found in 25 or more quadrats).
 - Bryum stenotrichum
 - Ceratodon purpureus
 - Dichodontium pallucidum
 - Funaria hygrometrica
 - Grimmia apocarpa
 - Grimmia stricta
 - Leptobryum pyxidiforme
 - Philanotis fontana
 - Leptobryum pyriforme
 - Pohlia cruda
 - Pohlia wahlenbergii
 - Racomitrium canescens
 - Racomitrium lanuginosum
2. Rather frequent - rather rare species: (found in 6-25 quadrats)
 - Atrichum undulatum
 - Bartramia ithyphylla
 - Barbula recurvirostra
 - Brachythecium salebrosum
 - Bryum argenteum
 - Campylium polygamum
 - Dicranella crispa
 - Distichium capillaceum
 - Drepanocladus uncinatus
 - Pogonatum urnigerum
 - Polytrichum alpinum
3. Rare species: (found in 2-5 quadrats).
 - Amblystegium serpens
 - Anomobryum filiforme
 - Aongstroemia longipes
 - Barbula fallax
 - Brachythecium albicans
 - Bryum calophyllum

Dicranella varia
Dicranoweisia crispula
Ditrichum cylindricum
Drepanocladus aduncus
Grimmia maritima
Grimmia torquata
Isopterygium pulchellum
Mnium hornum
Plagiomnium cuspidatum
Polytrichum sphaerothecium
Psilophium laevigatum

4. Very rare species: (only found in one quadrat)

Amphidium lapponicum
Aulacomnium palustre
Barbula ichmadophila
Barbula unguiculata
Barbula vinealis
Epachytheceum rivulare
Calliergon stramineum
Cephaloziella sp.
Dicranella heteromalla
Dicranella subulata
Ditrichum heteromallum
Encalypta ciliata
~~Encalypta sp.~~
Hypnum lindbergii
Marchantia polymorpha
Onchophorus virens
Pohlia prolifera
Polytrichum longisetum
Polytrichum piliferum
Racomitrium heterostichum
Rhytidiadelphus squarrosus
Scapania sp. (curta or scandica)
Solenostoma sp. (atrovirens or pumilum)
Trichostomum brachydontium

As each quadrat is a rather large unit, this frequency measurement may be considered somewhat crude. A thorough search for species inside each quadrat, however, gave a still better knowledge of the abundance of the species. According to this study, the moss species were grouped in the following three classes and given insignia which could be marked on a distribution map:

- The species is common in the quadrat, and found at ten or more locations.
- Less than ten individuals of the species occur in the quadrat.
- The species is only found once in the quadrat.

The maps shown on Plate 1-8 give the total number of moss species found on Surtsey in 1972 and illustrate their distribution and abundance per quadrat.

As is demonstrated on the maps, Funaria hygrometrica, which was one of the first moss species to arrive on Surtsey, is also one of the most abundantly and widely distributed members of the moss flora. The Racomitrium species arrived somewhat later, but have by now become the most dominant species on the island, especially R. canescens, which may also be considered one of the most common species that grow on Icelandic lava flows.

Species: *Bryum* sp.

Distribution of moss species 1971.

Species: *Bryum stenotrichum*.

Distribution of moss species 1971.

Species: *Comodon purpureus* (Hedw.) Brid.

Distribution of moss species 1971.

Species: *Euraria hygrometrica* Hedw.

Distribution of moss species 1971.

Species: *Racomitrium canescens* (Hedw.) Brid.

Distribution of moss species 1971.

Species: *Racomitrium lanuginosum* (Hedw.) Brid.

Distribution of moss species 1971.

Species: *Bryum argenteum* Hedw.

Distribution of moss species 1971.

Species: *Dichodontium pellucidum* (Hedw.) Schimp

Distribution of moss species 1971.

Species: *Disanella crispa* (Hedw.) Schimp

Distribution of moss species 1971.

Species: *Leptobryum pyriforme* (Hedw.) Wils.

Distribution of moss species 1971.

Species: *Pohlia cauda* (Hedw.) Lindb.

Distribution of moss species 1971.

Species: *Philonotis* sp.

Distribution of moss species 1971.

Species: *Polytrichum commune* (Webb & Mohr) Andr

Distribution of moss species 1971.

Species: *Allocladus undulatus* (Hedw) Beauv

Distribution of moss species 1971.

Species: *Barbula recurvirostra* (Hedw) Dicks

Distribution of moss species 1971.

Species: *Bartramia elyptrocarpa* Bruch

Distribution of moss species 1971.

Species: *Deschampsia flexuosa* Sw

Distribution of moss species 1971.

Species *Anthlystegium serpens* (Hedw.) BSG

Distribution of moss species 1972

Species *Phanobryum liliaceum* (Dicks.) Hwa

Distribution of moss species 1972

Species *Angstroemia longipes* (Swartz) L.B.S.G.

Distribution of moss species 1972

Species *Barbula fallax* Hedw.

Distribution of moss species 1972

Species *Brachythecium albicans* (Hedw.) BSG

Distribution of moss species 1972

Species *Bryum calophyllum* R.Br.

Distribution of moss species 1972

Distribution of mass species 1971.

Distribution of mass species 1971.

Distribution of mass species 1971.

Distribution of mass species 1971.

Distribution of mass species 1971.

Species *Mnium hornum* Hedw. --

Distribution of mass species 1971

Species *Oxyphloeus intricatus* (Hedw.) Brid.

Distribution of mass species 1971

Species *Pohlia arnoldiana* (Hedw.) Loeske

Distribution of mass species 1971

Species *Polytrichum alpinum* Hedw.

Distribution of mass species 1971.

Species *Polytrichum longisetum* Brid.

Distribution of mass species 1971.

Species: *Dicranella varia* (Hedw.) Schump

Distribution of moss species 1971.

Species: *Encalypta ciliata* Hedw.

Distribution of moss species 1971.

Species: *Fissidens adanthoides* Hedw.

Distribution of moss species 1971.

Species: *Grimmia maculosa* Turn.

Distribution of moss species 1971.

Species: *Grimmia stricta* Turn.

Distribution of moss species 1971.

Species: *Marchantia polymorpha* L.

Distribution of moss species 1971.

Species: *Acromobryum filiforme* (Dicks) Hust

Distribution of moss species 1971.

Species: *Bryum argenteum* Kindb

Distribution of moss species 1971.

Species: *Bryum arbuscula* (R Br) BSG

Distribution of moss species 1971.

Species: *Calliergon stramineum*

Distribution of moss species 1971.

Species: *Dicranella schreberiana* (Hedw) Schimp

Distribution of moss species 1971.

Species: *Ditrichum capillareum* (Hedw) BSG

Distribution of moss species 1971.

The species Bryum stenotrichum is listed in group (a) of common species, as it very likely is the main species of the Bryum population on Surtsey. However, this cannot as yet be determined for identification of each sample has not been completed. The various Bryum spp. were not fully developed when the samples were taken, and can only be identified and subsidized by differences in the characteristics of their peristome.

The same is the case with Philonotis, of which P. fontana is considered the main species representing that genus on Surtsey, although it has not been demonstrated with certainty except in cases of well-developed samples. This is also what may be expected, as P. fontana is the most common species of that genus in Iceland.

In the last few years there has been a great increase in abundance of the species Dichodontium pellucidum, Leptobryum pyriforme, Pohlia cruda, Pohlia Wahlenbergii, and Philonotis.

Even more spectacular is the rapid increase of Grimmia stricta. During the time between the studies in 1971 and 1972 its frequency jumped from being found only at one site to being the fifth most common species on the island. The same trend can be observed among the related species Grimmia apocarpa, which was discovered in only two quadrats in 1971, whereas in 1972 it inhabited 31 quadrats.

The local reproduction of moss:

Surtsey's original moss colonizers had to rely on dispersal of spores, which apparently derived mostly from the Icelandic mainland, by air. As the various moss species have become better established, they have gradually developed reproductive organs. In Table 3 are listed the species found bearing capsules in 1972, and a note has been made of the quadrat number where the capsule-bearing plants were found.

It is worth noting that the species Racomitrium lanuginosum was found bearing capsules on Surtsey for the first time in 1972, when quite a high number of capsule-bearing plants was found in four quadrats. This moss is the most common species on the Icelandic lava flows and will probably also eventually dominate the Surtsey lava. It was slower to invade the island and mature on it than many other moss species, but as the capsules have now developed the species has acquired greater possibilities of spreading.

It may also be added that the species Grimmia stricta and Grimmia apocarpa, which were rather rare in 1971 and have become common in recent years, are both bearing capsules and have thus a local source for spore dispersal.

Table 3

Capsule-bearing moss species in 1972
with location.

<u>Species</u>	<u>Quadrat No.</u>
<u>Funaria hygrometrica</u>	Capsules common in many quadrats
<u>Bryum stenotrichum</u>	" " " " "
<u>Dicranella crispa</u>	I8, H5, N14, 07, 011
<u>Grimmia stricta</u>	N17, N18, 017, P9, P10, Q11, Q13
<u>Grimmia apocarpa</u>	L17, M15, N14, I9, N17, N18, 016
<u>Racomitrium lanuginosum</u>	I18, L12, P11, Q12
<u>Barbula recurvirostra</u>	P11,
<u>Dicranoweisia crispula</u>	N12

The habitats:

In our studies of the moss vegetation on Surtsey the various habitats were recorded for each species observed in the different quadrats.

The classification was based on 4593 observations. Classical sociological measurements were not applied as the moss colonies are as yet rather scattered. But the records made give the frequency of the species per quadrat as well as the favoured habitat. The habitat classes, however, were based only on the topography of the lava, substrate, moisture and heat emission other microclimatic measurements being not investigated.

For evaluation of the habitats, the following categories were used:

1. Perpendicular lava cliffs in hollows and crevices.
2. Moist sand in caverns shaded by a block of lava, from where the condensed vapour drips onto the sand.
3. A thin layer of tephra on the lava surface fully-exposed with no effect from fumaroles.
4. Same as habitat 3 but affected by fumaroles.
5. The naked exposed lava surface without sand.
6. Hollows with sand, moist and somewhat shaded.

7. Narrow cracks in the lava filled with sand.
8. Sand, moist and warm from the fumaroles.
9. Sand covered lava with full light.
10. Sand on a lava slope, partly shaded and with more moisture than in habitat 9.
11. Naked and shaded lava slopes.
12. Sand at the bottom of a deep and narrow crack in the lava.

By classifying the species according to their abundance in any one habitat it is possible to show the environment favoured by the species. In Table 4, 23 of the most common species are listed according to their dominance in the moss flora of Surtsey, and in such a way that the first species on the list is the most common species on the island, and so on.

The frequency figures indicate how often the species were recorded in the various habitat classes. Thus, for example, the species R. canescens was observed altogether at 966 locations being in habitat class No. 5, on the naked exposed lava in 954 of the instances.

From this same Table it can also be seen that some of the habitats are common for various species, while others are only distinctive for one or a few species. Thus, class No. 5 is the most common habitat

Table 4

Samples of moss in Surtsey classified according to habitats.

Species:	Habitat class												Total observation
	1	2	3	4	5	6	7	8	9	10	11	12	
<i>Racomitrium canescens</i>	1				954	1	2	1	6	1			966
<i>Bryum</i> spp.	41	124	62	59	25	329	19	10	132	81	5	10	897
<i>Funaria hygrometrica</i>	25	72	23	23	13	274	22		216	82	1	6	780
<i>Racomitrium lanuginosum</i>	15	2			556	4	2	1	2			1	583
<i>Grimmia stricta</i>	13				331	4	5		1				354
<i>Ceratodon purpureus</i>	10	7	4	21	17	64	8	6	90	20	1	1	249
<i>Philonotis</i> sp.	8	5	4	13	2	70	1	4	20	30	1		158
<i>Pohlia cruda</i>	11	5		7	6	40	1		26	16			112
<i>Pohlia wahlenbergii</i>	7	4		6	2	59		5	8	5		1	97
<i>Bryum argenteum</i>			21	25		6			7	4			63
<i>Leptobryum pyriforme</i>	2	20		7		12		1	2	17			61
<i>Bartramia ithyphylla</i>	10			3	14	12			9	5		1	54
<i>Grimmia apocarpa</i>	4				46		1		1				52
<i>Dichodontium pallucidum</i>	5	1	2	5	4	20			6	7		1	51
<i>Dicranella crispata</i>	5		3	14	6	2	1	1	3	5			40
<i>Pogonatum urnigerum</i>				3		7		1	9				20
<i>Atrichum undulatum</i>	3			3		4		1	4	3			18
<i>Drepanocladus uncinatus</i>	3				6	3			2	2			16
<i>Campyllum polygamum</i>	6				3	2			1	1	1		14
<i>Distichium capillaceum</i>	3				2	1			2	1			9
<i>Polytrichum alpinum</i>				2		4			2				8
<i>Barbula recurvirostra</i>	3	2								2			7
<i>Brachythecium salebrosum</i>	1	1			1	3				1			7
Total	176	243	119	191	1988	921	62	31	549	283	9	21	4593

on the island. It is favoured by various species, such as the two most common Racomitrium and two Grimmia species. These four species seem to thrive well on the island, but they have not yet had the competition to show which species will eventually dominate in the various moss communities. Several other species were found growing in this habitat. But they are, so far, only associate species in this primary succession. One example of the associate species is Bartramia ithyphylla which also grows under various other conditions.

Another common habitat on Surtsey is the sand-covered hollow, classified as No. 6. It is favoured by many species of moss, such as various Bryum species, e.g. B. stenotrichum and Funaria hygrometrica, which are the most dominant species, and also a number of associate species, such as; Philonotis, Pohlia cruda, Pohlia Wahlenbergii and Dichodontium pellucidum.

Other habitats are more rare and have specialized conditions. These are, for example, occupied by species that require more abundant moisture and shading conditions than the common species.

The cover:

The total cover of moss in Surtsey is still rather sparse and difficult to measure due to the rough surface of the lava. The cover of each species in every quadrat was evaluated in such a way that the present cover was recorded within a 25 x 25 cm frame at ten locations within a quadrat. On the maps (Fig. 1) the cover evaluation is given in average percentages for four common species.

It may be noted that the cover estimates vary according to species and their position in the lava. The species Bryum (mostly B. stenotrichum) and Fumaria hygrometrica have obtained the most extensive cover, the Racomitrium being second in coverage. Others have less average cover per quadrat.

If the distribution and cover maps are compared, it may be noted that cover estimates do not always follow the frequency classes. Where the frequency classes are high the cover estimate is most reliable.

Fig. 1

Species: Bryum spp.

Species: Racomitrium canescens (Hedw.) Brid.

Species: Funaria hygrometrica Hedw.

Species: Racomitrium lanuginosum (Hedw.) Brid.

0 - 10,0 % Cover
 1,1 - 100,0 % -
 > 100,0 % -

The biomass of the vegetation on Surtsey and Heimaey 1972.

The organic matter produced on Surtsey every year has been negligible so far. In 1971 a quantitative measurement of the biomass of moss was performed in the three quadrats showing the densest cover. The maximum biomass was found in quadrat M11 giving an average of 1.020 g/m^2 . Other areas had a much lower biomass.

In the late summer of 1972 the measurements of biomass were continued in the same manner as in the previous year. Samples of moss were collected from the areas that had the densest moss growth. These were sites in quadrats J8, M11 and L18.

The calculated biomass from each area is shown in Table 5.

The total average in 1971 was 0.518 g/m^2 compared with 3.076 g/m^2 in 1972, so there has been a large increase in the quantity during this one year. The high average is mostly due to one sample from a dense cover in quadrat J8.

For comparison, measurements of biomass were taken on Heimaey in three different plant communities in 1972.

These figures indicate how small the biomass of the Surtsey communities is in comparison with the productive and well established communities on Heimaey.

The biomass was also measured in 1973.

Table 5

Biomass of vegetation from Surtsey and Heimaey in g/m².

	Communities	Quadrat	Average
<u>Surtsey 1971</u>	moss	J-8	0.338
	moss	K-18	0.196
	moss	M-11	1.020
Total average			0.518 g/m ²
<u>Surtsey 1972</u>	moss	J-8	8.671
	moss	L-18	0.096
	moss	M-11	0.460
Total average			3.076 g/m ²
<u>Heimaey 1972</u>	Meadow land		828,5
	Heath vegetation		898,1
	Puffin ground vegetation		991,5
Total average			906,1 g/m ²

The vascular plants.

Earlier I have stressed the point that seed and other diaspores of vascular plants drifted to the shores of Surtsey and dispersed to the island by various other means shortly after it was formed and while the volcanoes were still active.

A number of seeds were collected on the shore in 1964 and proved viable and capable of germinating, although no vascular plant started growing during this first summer of the island's existence. But it was considered likely that pioneers of vascular plants would soon be found growing along the shore.

After searching the island thoroughly in the second summer, I discovered the first higher plant on Surtsey 3 June 1965.

Small seedlings of the sea rocket Cakile edentula were found growing upon the sandy beach north of the small lagoon on the island. During a later expedition in June the same year, some 20 additional seedlings of the same species were discovered approximately 50 m east of the previous location.

The plants were all growing in a mixture of tephra and decaying thalli from the seaweed (Ascophyllum nodosum), which evidently formed a suitable medium for the germination and growth of the young plants, as the

Cakile is apparently quite nitrophilous.

The plants had grown from seed that obviously had been washed ashore, possibly along with the seaweed, which might act as a float, aiding dispersal of seed by ocean.

The seedlings of these pioneer colonists, however, did not mature, and succumbed a few weeks later under a shower of ashes carried from the volcanic crater Syrtlingur. The fall of fresh tephra from this satellite volcano thus delayed the colonization of higher plants on Surtsey for one year.

The discovery of the Cakile plants on Surtsey showed that living seed could be carried by sea at least 20 km, which is the distance from the island to Heimaey, the nearest colony of Cakile.

The second attempt of higher plants to invade Surtsey took place during the summer of 1968. On July 2 four seedlings of Sea Lyme grass, Elymus arenarius, as well as a seedling of sea rocket were found growing on the sandy shore on the northern side of the island.

The plants grew from seeds that had apparently also dispersed by sea, as they were all found growing in a zone at the hightide line. They were subjected to a similar fate as the plants that had made an attempt to colonize in the year before. This time, however, the colonizers were wiped out by ocean waves sweeping over the low sandy beach.

The summer of 1967 was more favourable for colonization, and a third species attempted to invade the island. This was the sea sandwort, Honckenya peploides, a common perennial on the southern shore of Iceland. During the summer, 26 individuals of this species were recorded, a number of which produced considerable vegetative growth. The fourth species on the island was the oyster plant or the lungwort, Mertensia maritima, a perennial of which only one specimen was found on the "New Year" lava by the lagoon. The two former colonizers were also represented. A few plants of sea lyme grass were found on the sand and pebbles at the hightide mark, as well as 21 individuals of sea rocket that grew here and there on the ness of which 15 flowered and six bore mature pods. Plants of the latter species were thus the first to flower on the island. They set approximately 300 pods with twice as many seeds. The sea rocket was, therefore, the first of the colonizers to succeed in multiplying in the new habitat and in laying the foundation for a new generation of plant on the island of Surtsey.

It was therefore surprising that no sea rockets showed up in 1968. The reason for this is not known, but the species is an annual, and neither old plants nor the seed from the last year's crop seem to have survived. The H. peploides plants, on the other hand, had increased in number and were now found growing further up on the lava to the east, where they were better sheltered from the waves and wind in the sand-

covered lava. In 1969 still another vascular species was added to the island's flora. This was the scurvy grass Cochlearia officinalis, which is common to the coast of Iceland and is found on the skerries and larger islands in the Westman archipelago. Four plants belonging to this species were found growing near one of the plastic barrels filled with rain-water used to attract birds, this being the only source of fresh water on the island. These plants had obviously been carried as seed by birds to the barrels, and it was noted that the plants, beside the barrels, were growing out of bird droppings in association with the algae previously mentioned. The total number of plants found on the island that year was reduced because of a rather unfavourable spring and summer.

On the other hand, some of the H. peploides plants had over-wintered, and one these developed 49 flower buds. Most of these sandworts were growing among drifted seaweed on the northern ness, located at the edge of the New Lagoon, which had been filled up by sand during the winter. The fertilization by the seaweed may, to some extent, have stimulated the growth in this drift zone. On the mainland the sandwort is a pioneer on the sandy shore, particularly on the fore-dune.

In 1970, the major event was the discovery of still another vascular species; the common chickweed, Stellaria media. A close scrutiny revealed that there were, in fact, four plants growing together in a

compact bunch out of a sand-filled lava crack. Around them were fragments of shells, bird droppings and feathers, and it was obvious that the plants had grown up from the droppings of a bird. These plants matured and set 12 fruits. Some of the seeds ripened and dispersed from the plants during late summer. This year the scurvy grass plants had also increased in number. These had apparently also grown from seed that birds had carried to the island.

An exceptionally large percentage of vascular plants survived the winter of 1970 to 1971, or 40 out of 75, and only a few were added, to the total number reached 57 individuals. Both that winter and spring were unusually mild, and as most of the plants had been growing in the rather sheltered parts of the ness and up on the lava edge to the east, they had a better chance to overwinter than individuals in previous years. In extensive areas of the lava, an increased amount of tuff and ash had drifted in from the tephra mounds.

At first the sand accumulation in the lava had mainly taken place in the old lava on the western side and consisted partly of tephra from the island of Jólnir, but gradually the lava filled up by drifting sand coming from the eastern edge of the coastal plain as well as the tephra cone. This may to some extent explain the increased distribution of plants in the lava apron that took place this year.

During a detailed search for plants in the lava we came upon three small ferns that were growing down from a cave roof. This turned out to be a small individual of the bladder fern, Cystopteris fragilis, which is the most common fern in Iceland and grows both on the post glacial lava as well as on other rocks and cliffs. The plants on Surtsey had reached two to three cm length when first observed and kept on developing, as they were sheltered and shaded from the direct sunlight.

Until this time there had been an addition of approximately one new species of vascular plants to the island's flora every year since the colonization of these plants started. However, in 1972, at least four new species were discovered. These were: Angelica archangelica, Carex maritima, a Puccinellia species, and Tripleurospermum maritimum syn. Matricaria maritima. All of these species are common on other islands in the Westman archipelago or on the lava flows of the mainland.

The Angelica species was represented by two small seedlings with the cotyledons and seedwall attached. They were growing at the hightide mark on the northeastern part of the ness, which indicated that the plants developed from seed which had drifted to Surtsey by the ocean.

A small grass plant had been growing on the lava in quadrat M11 for some time. It was first incorrectly

recorded in 1970 as a seedling of sea lyme grass but was in 1972 definitely identified and listed as the sedge Carex maritima. The plant had not produced any flower stalks, but it had developed stolons and was by that time increasing vegetatively so that several new individuals were being formed beside the mother plant.

The third new species was the goose grass, Puccinellia, very likely of the species maritima, which is common on other islands and skerries in the neighbourhood. Two individuals representing this species were growing near one of the sites where a water container had been placed. This site, like the others where traps had been set up to catch fresh water micro-organisms, was frequently visited by birds. It is therefore very likely that these two plants also developed from seeds dispersed to the area by seagulls or other frequent bird visitors.

The fourth new species discovered in this year was the mayweed, Tripleurospermum maritimum syn. Matricaria maritima, a very common species on all the Westman Islands. The first plant of the species on Surtsey grew on the southern edge of the lava apron in a sand, covered hollow, which was also occupied by individuals of scurvy grass. It is likely that all the plants in the same hollow grew from seed brought to the edge of the lava rocks by birds, which often roost on these southern rocks or fly along the shore.

During the summer 1971 there were 83 vascular plants on Surtsey, of which 49 individuals survived the winter 1971-72 or 59%. This was an even higher percentage of surviving individuals than the year before. The majority of the individuals that year were growing in the relatively secure sites of the lava, with fewer individuals on the northern ness than in previous years. This latter location is often overflooded during winter storms and is thus quite hazardous for the overwintering of plants. The corresponding percentages of overwintering plants for the previous winters are: 20% in 1968-69, 35% in 1969-70, and 53% in 1970-71, the graph on Fig. 11 shows the number of vascular plants growing on Surtsey during the years 1965 to 1973, as well as the number of overwintering plants for the last five years. It is obvious that each year an increased number of plants survive the winter. This must be due to the more secure location of growth and a steady increase of permanent members of plants.(Table 6).

During the early years of colonization Honckenya peploides was the most abundant plant on Surtsey, but in the summers of 1972 and 1973 the individuals of Cochlearia officinalis outnumbered all the other species. This is mostly due to the fertility of one plant, which produced a number of offsprings in both 1972 and 1973, and has formed a small colony of scurvy grass on the south where. The graph on Fig. 12 shows the annual increase in

Fig. 11

Total number of vascular plants on
Surtsey and their overwintering.

Fig. 12

vascular Table 6
List of plants on Surtsey which have lived for two years
or longer, with their location and identification

Species	Quadrat	Number	Years of growth.						
			67	68	69	70	71	72	73
<i>Carex maritima</i>	M-11	70-72				x	x	x	x
<i>Lochlearia fr. inalis</i>	J-18	70-18				x	x		
-	K-18	70-29				x	x		
-	K-18	70-31				x	x	x	x
-	L-17	70-10				x	x		
-	L-17	70-10				x	x		
-	N-13	71-75					x	x	x
-	O-6	70-19				x	x	x	
-	P-10	71-11					x	x	x
-	P-17	71-57					x	x	x
-	P-11	71-75					x	x	x
-	S-14	70-74				x	x	x	x
-	S-14	71-54					x	x	x
-	S-14	71-55					x	x	x
-	S-14	72-34						x	x
-	S-14	72-37						x	x
-	S-14	72-41						x	x
-	S-14	72-42						x	x
-	S-14	72-44						x	x
-	S-14	72-45						x	x
-	S-14	72-53						x	x
<i>Cystopteris fragilis</i>	I-8	72-113						x	x
-	N-9						x	x	x
<i>Elymus arenarius</i>	F-15	67-23	x	x					
<i>Honckenya peploides</i>	D-12	70-37				x	x	x	x
-	E-11	70-47				x	x		
-	E-11	70-48				x	x	x	
-	E-11	70-55				x	x		
-	E-11	70-56				x	x	x	x
-	E-11	72-99						x	x
-	E-11	72-100						x	x
-	E-12	68-48		x	x				
-	E-12	68-?		x	x				
-	E-12	69-42			x	x			
-	E-12	70-35				x	x	x	x
-	E-12	70-43				x	x	x	
-	E-12	70-53				x	x	x	
-	E-12	70-54				x	x	x	x
-	E-13	68-?		x	x	x			
-	E-13	69-62			x	x	x	x	x
-	F-13	70-42				x	x	x	x
-	F-13	70-60				x	x	x	x
-	F-13	70-69				x	x		
-	F-13	71-43					x	x	x
-	F-13	71-45					x	x	x
-	F-13	71-56					x	x	x
-	F-13	71-47					x	x	x

Species	Quadrat	Number	Years of growth					
			64	69	70	71	72	73
<i>Honckenya perfoliata</i>	F-14	72-83					x	x
-	F-14	68-1	x	x				
-	C-15	70-39			x	x	x	x
-	C-15	68-102	x	x				
-	C-15	68-103	x	x				
-	T-4	71-35				x	x	x
-	L-4	71-68				x	x	x
-	F-14	72-111					x	x
-	-	68-63	x			x	x	x
-	-	71-67				x	x	
-	-	72-30					x	x
-	J-13	71-63				x	x	x
-	J-17	68-6	x	x	x	x	x	
-	J-17	68-24	x	x	x	x	x	
-	J-1	70-25			x	x	x	
-	J-13	68-3	x	x				
-	J-14	68-4	x	x	x	x	x	x
-	J-18	68-8	x	x	x	x	x	x
-	J-18	68-21	x	x	x	x	x	x
-	J-18	68-22	x	x	x	x	x	x
-	J-18	68-23	x	x	x	x	x	x
-	J-18	68-64	x	x	x	x	x	x
-	J-18	68-70	x	x	x	x	x	x
-	J-18	68-87	x	x	x	x	x	x
-	J-18	69-50		x	x			
-	J-18	70-4			x	x	x	x
-	J-17	70-20			x	x	x	x
-	J-18	70-30			x	x	x	
-	J-18	70-64			x	x	x	x
-	J-18	72-109					x	x
-	K-5	72-56					x	x
-	K-17	68-83	x	x	x	x	x	x
-	K-18	68-56	x	x	x	x	x	x
-	N-10	71-69				x	x	x
-	M-10	72-108					x	x
-	R-17	68-101	x	x	x			
-	R-17	68-2	x	x				
<i>Puccinellia</i> sp.	R-14	72-90					x	x
<i>Stellaria media</i>	R-14	71-115					x	x
<i>Tripleurospermum maritimum</i>	S-14	72-40					x	x

individual numbers of these two most frequent species of vascular plants on Surtsey indicating also the proportion of overwintering plants every year.

The distribution of plants increased heavily in 1973. In 1972 there were 199 individuals discovered in 41 quadrats of the 234 quadrats covering the dryland on Surtsey. Five more quadrats were occupied by plants in 1972 than in the previous year. In 1973, the number of individual plants jumped to 1273, and these occupied 58 quadrats. The increased distribution of vascular plants on Surtsey can be shown by the number of quadrats the plants have occupied in the various years. The graph on Fig. 13 shows that there is a steady increase of occupied quadrats during the last five years.

In Table 7 is a list of species of vascular plants found on Surtsey during the past nine years. It is noticeable that the first colonist, which was the sea rocket, Cakile edentula, has not become a permanent member of the plant colony. It is an annual plant and, although it has produced seed on the island, it has to rely on the annual seed maturity and seed supply to the island as well as on the growing conditions at the tide mark. The Cochlearia officinalis occupies a more secure location and develops seed earlier than the Cakile. Plants of Honckenya peploides are the most permanent colonizers. They are perennial and are gradually increasing in size and development of flowering branches.

The main location of the vascular plants during the summer of 1973 was, in general, the same as in previous

Name of species	'65	'66	'67	'68	'69	'70	'71	'72	'73
<i>Cakile edentula</i>	23	1	22		2			1	33
<i>Elymus arenarius</i>		4	4	6	5	4	3		66
<i>Honckenya peploides</i>			24	103	52	63	52	71	548
<i>Mertensia maritima</i>			1	4				15	25
<i>Cochlearia officinalis</i>					4	30	21	98	586
<i>Stellaria media</i>						4	2	2	1
<i>Cystopteris fragilis</i>							1	4	3
<i>Angelica archangelica</i>								2	2
<i>Carex maritima</i>								1	1
<i>Puccinellia</i> sp.								2	1
<i>Tripleurospermum maritimum</i>								1	5
Unidentified plants				1			4	2	1
<i>Festuca rubra</i>									1

Table 7

Total number of vascular plants annually found growing on Surtsey

years; east of the tephra cone, Strompfjall in quadrats J17 and J18, near the hut in quadrats E12 and E13, and in the Black Gully quadrats F13 and G13. The fourth location was on the northern ness, and the fifth site has been named the Light Hill, S14, on the southern part of the lava where a number of plants were found occupying an area of 80-100 sq m.

The study of vascular plants has been performed in such a way that during every year continuous observations are made throughout the summer.

As new individuals are found, their location and stage of growth is recorded and their progress of development followed during the summer. Every plant is then marked with a stake bearing a specific number. The positions of all plants are finally plotted on an aerial photograph. Every year these locations have then been drawn on a map of the island, which also bears the grid of checkers or quadrats identified numerically and alphabetically. The locations of all the higher plants found on the island from the beginning can thus be detected and are shown on the map series.(Fig.2-10). On the same maps the total distribution of moss is also plotted.

By comparing the maps from year to year, it may be noted that the invasion of higher plants has mostly come towards the northern ness. The vegetation there has been unstable, and some seed have apparently been blown around the eastern side of Strompfjall and up towards the lava edge.

These plants enjoy a greater security than the individuals out on the ness, and the site is sheltered from the north wind. Except for the colony at Light Hill there is only a sporadic occupation of higher plants on the lava apron.

In contrast to the moss vegetation, which has mainly occupied the lava, the higher plants have largely settled on the sandy beach and gradually invaded the sand-filled hollows of the lava. There they have joined the moss in forming the juvenile community, which often only consists of one higher plant, a few moss species, an odd algae, moulds, and bacteria. Most of the individual plants, however, are still so far apart that one can hardly speak of a community, and there is only a slight relationship between the colonization of moss and the vascular plants. They are dispersing to the island and occupying their habitats independently. The bacteria, that have been found growing on the organic matter secreted by the plants are, however, obviously, dependent on the latter.

The terrestrial animals

So far there has not been a great deal of organic matter produced by the terrestrial vegetation on Surtsey, and the producers have thus not been able to support any substantial amount of life occupying higher trophic levels. Most of the animals observed on Surtsey are, therefore, visitors that obtain their energy from sources not directly belonging to ^{the} island's ecosystem. A few of the animals may be considered partial occupants, and some have reproduced on the island although their food is sought away from their breeding site. Still a smaller number of individuals may be listed as permanent colonizers of Surtsey.

The micro fauna

In the surface tephra just above high tide line marine algae are washed up with the ocean spray. There this organic matter is used as food by bacteria, fungae, and a few lower animals. In 1968 this substrate was sampled and an analysis performed to determine whether species of lower animals were present and to investigate their composition and abundance.

The tephra samples were examined microscopically for amoebae, testacea, flagellates, and ciliates. This was performed after a 2-3 g portion of the tephra had been spread out on agar plates with different culture media and an addition of the bacterium, Aerobacter, which was used as a food source.

This examination revealed that only flagellated protozoa (Class Mastigophora) were present. The identified species were Oikomonas termo, (Order Chrysomonadida), Phalansterium solitarium, Sainouron mikroteron (Order Protomonadida), and Helkesimastix faeicola (Order Rhizomasfigida). The quantitative determination of the individuals showed that there were on the average only 290 flagellates in a gram of tephra, both mobile cells and cysts. This is a much lower number than would be found in the soil of a highly developed grassland community. These flagellated protozoa may be pioneer species of the Surtsev sub-rate. They can easily disperse to the island by wind and be carried on, or with dust particles. They may be the first to appear, as these species have lighter spores than most other protozoa. Above the hightide mark the organisms find their appropriate food source, and in this habitat they become the primary consumers of the ecosystem.

Higher up on the island, near fumaroles and other moist spots in the Surtur craters where algae and moss have gradually established their first colonies, the microfauna may find adequate food supply, and there the various airborne spores dispersing to the island have a ^{fair} chance of developing.

In 1970 some of these locations were visited and samples taken from patches of algae and moss growing in lava caves and on edges of fumaroles with moist surfaces formed by the condensed steam. After culturing the vegetation samples on nutrient media of a solid or liquid substrate, different microzoa were discovered. These were individuals belonging to the amoebae such as Valkampfia, Naegleria, and Thecamoeba species, and Testacea such as Euglypha species. Of the ciliates the species Cyclidium citrullia could be identified, as well as two species of bdelloid rotifers. All of these forms are considered to be cosmopolitans and capable of reproducing asexually. The animals are readily transformed into resting forms and can in this stage be transported to the island. These microzoa are all capable of withstanding severe environmental changes such as drought and frost. It is, therefore, clear that they are capable of being the pioneer consumers at the lower trophic level of the food chain in ^{the} moist lava habitat on Surtsey, where they feed on ^{the} blue-green algae, Nostoc, and bacteria.

It should also be pointed out that already in 1971 two nematodes; Acrobeloides nanus and a species of Monhystera, were discovered on

the island, although these individuals were obtained from the rather artificial habitat of the fresh water container so often mentioned in previous chapters of this book. At least, the former species is comparable to other animals so far observed in the microfauna of Surtsey with respect to reproduction, distribution, and the ability to withstand severe environmental conditions. The A. nanus nematode is a cosmopolitan species with a wide distribution in Europe. It is partheno-genetic and has the ability to survive desiccation, so that these individuals can, better than many other animals, endure drought and thus successfully manage to disperse to Surtsey. They are bacteria-feeders, and occupy a very low trophic level.

The terrestrial invertebrates

The first specimen of terrestrial invertebrates was a diptera fly, later identified as that of Diamesa zeryni. It was collected by me on May 14th 1964 on the western shore during the first spring of the island's existence, only half a year after the island's formation. The following summer five more specimens of flies and midges were collected, as well as two species of moths and the mite Thinoseus spinosus. It was especially interesting to note that the mite was apparently living on some dead midges and the Leria modesta, which is a common fly on neighbouring islands. The fly, in turn, was living on the carcass of a bird so a food chain was already established, starting with the carcass, continuing to the mite, and ending in a mould that was found living on one of the mites.

In 1966 glue-traps were set up on the island to capture flies, and a systematic collection of terrestrial arthropods started (begun). During that year 22 species of insects were recorded and four species of arachnoidea. Since then a number of new species of arthropods are recorded every year that passes. In the year 1967 56 species of insecta and seven species of arachnoidea were collected, and in 1968 there was an addition of eight new species. In the years 1969 and 1970 the number had increased to 112 species of insecta and 24 of arachnoidea.

This large number of Arthropods so far discovered on Surtsey does not imply that the animals have all started colonizing the island. On the contrary, the majority of them are only casual visitors and a very few may be considered permanent inhabitants.

The number of insect species already recorded on Surtsey may be considered high in relation to the total number of insects known in Iceland, or 158 species of the 750 species which are known to have been found in the country - indicating that dispersal of insects to the island must be relatively easy.

As stated in the chapter on dispersal, there are several means of transport for the various terrestrial invertebrates; by own wing support, by wind, water, other animals, and man.

- 1) Many species of butterflies and moths have so far been recorded on Surtsey. In 1966 I found a specimen of Plusia gamma, which is not native to Iceland but migrates from the mainland of Europe, or from the British Isles. It and other Lepidoptera are excellent flyers and migrate over long distances on their own wing support.
- 2) All the insects discovered on Surtsey are winged, but it is doubtful that they could have managed to reach the island if they were not also aided by favourable winds. It has, for example, been noted that during strong northerly winds 10 to 20 m/sec. the number of airborne individuals has increased markedly. Most of the 77 diptera species are, as a result of this, considered to have reached Surtsey by these means of dispersal.

Ballooning of spiders is one way of dispersal which is aided by wind. In 1966 a small living spider of the family Linyphiidae was discovered on the northern ness of the island. This spider had apparently been ballooning on the long thread secreted by the animal, especially during the immature stage.

3) On a few occasions it has been possible to demonstrate that insects may be transported to Surtsey by sea. Such may have been the dispersal of the mite Oribotritia faeroensis, which was discovered on the island in 1966. The eleven individuals of this species were found alive on a gate-pole, which very likely had drifted to the island from the dumps on Heimaey. In a similar way the weevil Otiorrhynchus arcticus must have been carried to the island, as it is not able to fly. It is abundant on Heimaey and could have been transported by some kind of floats, but hardly by direct transport in the ocean, as experiments have shown that it does not survive immersion in water more than 24 hours.

4) It was demonstrated during our bird collection that a number of birds were carrying insects on the exterior of their bodies, and even in their alimentary tracts, but some insects are also found to have mites (Acaria) in their nymphal stage as parasites, and have in that way transported mites to the island.

5. Although there are strict regulations regarding ^{the} import of plants and animals to Surtsey, man has brought at least two flies, Drosophila funebris and Musca domestica, to the island. These two species were found inside the scientists' hut and were very likely transported with the latter's provisions.

Origin and colonization

The immigrating invertebrates so far collected on Surtsey have mostly derived from the other islands of the archipelago. The insect fauna of these islands was consequently investigated in 1968, so that it is now possible to determine which of the animals hitherto found on Surtsey could have derived from these islands and thus also the shortest possible distance of dispersal. Heimaey being the largest of the islands, also has the greatest number of invertebrate species and has, very likely, supplied Surtsey with a number of immigrants. It has also been demonstrated that some of the individuals found on Surtsey must have come from the mainland of Iceland, as no representatives of the same species are found on the Westman Islands. Some of the active flyers, such as the Noctuid moths and butterflies, must even have derived from Europe,

as they are not native to Iceland. These individuals have therefore dispersed over the Atlantic with air-currents and finally landed on the island. It must be borne in mind that the greatest number of individuals belonging to the various species of terrestrial invertebrates so far found on Surtsey are only casual visitors that happen to be carried to the island and have little chance of survival. A small number have been able to live for any length of time, and only a few of these have been able to breed and may be considered to have become temporary or permanent inhabitants. The main hindrance to a successful colonization is the lack of available food supply for the animals in this new habitat, as the vegetation has, until recently, not produced any substantial amount of organic matter. The major food source has been the organic matter washed ashore from the sea. Insects that can breed and rear their offspring on such carcasses have therefore had the best chance to colonize. The three following species are all terrestrial invertebrates that have occupied the beach on Surtsey.

1) In 1966 the fly Leria borealis was discovered and later found to be breeding abundantly in carcasses of fish and birds on the coast of Surtsey. Since then this fly has been breeding periodically on the island,

but its survival depends on the availability of food and sea gulls are hard competitors, devouring rapidly any carcasses washed upon the shore, so food is not permanently available.

2) The first collembola Anistoma besselsi was discovered on Surtsey in 1967. It spreads easily with the sea currents along the coast of Iceland and has apparently been dispersed on the ocean surface to Surtsey, where it has colonized the beach and become abundant and a permanent inhabitant.

3) In 1970 a chironomid midge Cricotopus variabilis was found breeding in shallow pools at the tidal zone on Surtsey. This midge is common on Heimaey and it is reasonable to think that it has become a permanent resident on Surtsey.

All these individuals are finding enough food source on the beach and are capable of surviving and reproducing in the coastal habitat of the island, but farther inland no invertebrates have yet had a chance to colonize.

The birds

Sea-gulls were among the first living creatures to set foot on Surtsey, and they have continued to soar about its beaches, or roost on its hills and cliffs ever since. The ocean around the Westman Islands is extremely rich in marine life used by various birds as a source of food. Sea-gulls and waders feed on carcasses of marine animals cast ashore on the island, or make their catch from the ocean further out and sometimes bring their prey ^{onto} dry land to devour it there. The remnants of such carcasses ^{an} may, in turn, serve as an energy source for lower forms of life. The presence of Sea-gulls on the island also greatly affects the future soil of Surtsey by their excreta supplying fertilizer, containing both minerals and organic matter. This is mainly deposited along the edge of the cliffs of the southern coast, on the sandy beach of the northern ness and on high peaks of the tephra cones. As previously mentioned the birds have played their part in transporting diaspores of plants to Surtsey and are even carriers of various invertebrates. The birds are therefore very important members of the island's ecosystem, but until the present time they have mostly had to rely upon an energy source obtained from outside the boundaries of the island.

From the very beginning of the Surtsey research various observations were performed with regard to birds visiting the island. Records have been made, by skilled bird-watchers, of birds seen since the formation of the island. And, during certain periods in early spring and autumn, birds have been collected for closer examination by ornithologists. In the spring migratory birds fly north from the continent of Europe and the British Isles, frequently visiting Surtsey, which is the first possible landing place for a number of these birds after crossing the Atlantic. In the autumn the birds have a reverse route when flying south from Greenland or the mainland of Iceland, ^{and} they may have a short visit on Surtsey. During such a visit the birds sometimes empty their guts and deposit seed with their excreta. I have witnessed a flock of geese in flight over the island bombing it with their droppings as they became disturbed by the presence of man on the island.

During the autumn, Iceland is often visited by drift migrants from northern Europe or Siberia that are making their journey south by the west coast of Europe and drift off their course over the Atlantic. Many of such stragglers that have been seen or caught on Surtsey may also be carriers of seeds, which are abundantly available at this time of the year. The ornithological work on Surtsey has been important in demonstrating the exact time of arrival of the various migrants to Iceland,

their physical condition after the flight across the ocean, the part they may play in transporting other organisms as well as their exodus in the autumn.

Of the 230 species recorded as seen in Iceland, 60 have so far visited Surtsey. Following the first visit of the Sea-Gulls a group of Redwings, Turdus iliacus, were seen in the early spring of 1964. In May, the same year, I observed a Snow Bunting, Plectrophenax nivalis, up in the lava and a few Dunlins, Calidris alpina, and Oystercatchers, Haemotopus ostralegus, feeding on the Euphausiids that had been washed ashore on the northern side of the island. The birds most frequently seen, however, were the Sea-Gulls, such as Larus and Rissa sp. The Kittiwakes, Rissa tridactyla, may have been the first of the Sea-Gulls to alight on the island during intervals between eruptions, and in 1964 a flock of these birds frequently rested ^{on} the tephra bluffs on the northern side, or vertical cliffs of lava that had been formed on the southern side of the island.

The great black-backed Gull, Larus marinus, occupied the flat sandy beach and was accompanied by the herring Gull, Larus argentatus, and the glaucous gull, Larus hyperboreus, in varying numbers during the first summer as well as the arctic tern, Sterna paradisaea.

In early August a large flock of Red-necked phalaropes, Phalaropus lobatus, were swimming close to the shore and later in the autumn an oiled specimen of a common Guillemot, Uria aalge, was encountered. A single Turtle Dove, Streptopelia turtur, was seen on the lava flow on the southwestern part of the island in October. This last species is an irregular straggler that has drifted off its course and could possibly be one of the best carriers of seeds, if it flew with a full crop to the island.

In 1965 a pair of ravens, Corvus corax, occasionally visited the island and was seen there frequently in the following years. During that summer four additional species of birds were recorded.

In 1966 23 species were recorded as seen on the island, among which was a Merlin, Falco columbarius, that flew over the lava in search of prey, which may have been the Wheatear, Oenanthe oenanthe, seen during the same period, as well as a few other Passerines. A Merlin had been seen eating a Wheatear on Surtsey, and later several carcasses of Wheatears and Meadow Pipits, Anthus pratensis, were observed. These birds, in turn, may have been feeding on insects that obtained their energy source from a still lower trophic level.

In 1967 there were 29 species of migratory birds observed on or around Surtsey, besides the 13 species of resident sea-birds that frequently occupy the neighbouring islands. Among these were Redshanks, Tringa totanus and Golden Plovers, Pluvialis aprincaria, in addition to several species of geese such as the Greylags, Anser anser, Pinkfeet, Anser brachyrhynchus, and a number of Barnacle geese, Branta leucopsis, that either flew over the island or settled on the plains of the northern ness. One long-eared Owl, Asio otus, was caught in the lava that spring, where it was apparently seeking some prey. This was available in abundance among the exhausted Passerine migrants such as the White wagtail, Motacilla alba, which was frequently seen catching flies around the scientists' hut.

The following year (1968) a Whooper Swan, Cygnus musicus, visited the island, as well as several ducks; Mallards, Anas platyrhynchos, Teals, Anas crecca, Widgeons, Anas penelope, and the Red-breasted merganser, Mergus serrator.

Among birds collected or observed in 1969 was a Squacco heron, Ardeola ralloides. This bird was new to Iceland.

Such a discovery could be expected, as Surtsey is situated farther south than any other part of

Iceland and the stragglers are most common on the southern shores of Iceland in the autumn. During this same summer nine other drifting migrants were encountered. Among them was a short-eared owl Asio flammeus, a European robin Erithacus rubecula and a jackdove Corvus monedula.

In the year 1970 a number of new visitors were spotted on the island such as: Cornorake, Crex crex, a Willow warbler, Phylloscopus trochilus, and a Wedstart Phoenicurus phoenicurus, and with every passing year the number of bird species seen on the island increases.

Most of the drifting migrants are only unusual rarities that do not play any major role in the island's ecosystem. The major influence is without doubt exerted by the local sea birds and the great populations ^{of migrants} that fly across the island regularly every spring and autumn.

Migratory birds coming from Iceland may fly over Surtsey in a southerly direction towards the British Isles, where they winter, or they may proceed to France, to the Iberian peninsula or all the way to West Africa. In the spring the route is reversed; the migrating birds head north and start arriving in Iceland in April. Much information pertaining to migration routes has been accumulated by using bird banding, but thorough

studies on the time of arrival and exodus of these birds by direct observation methods had not been practised in Iceland to any extent until the research began on Surtsey.

As Surtsey lay in the path of the migrating birds, it was considered to fulfil requirements for such a study. The island was therefore manned by experienced bird-watchers, both in spring and autumn, from the year 1967 to 1970. They observed the migration of birds and kept records of all birds seen on the island and in its vicinity. The main stream of migrants arrives at the southeastern part of Iceland, leaving Surtsey somewhat off the direct route. During side-winds arriving birds ^{however,} may, in some years drift in great numbers to the island.

The Redwing and the Golden plover are early arrivers and are followed after mid-April by various waders, such as Redshanks Tringa totanus or turnstones Arenaria interpres, which were often seen in hundreds during their stop-overs on Surtsey. In late April and the first days of May geese and various small passerines may visit the island in large numbers.

During the migration studies 100 to 200 individuals of 10 to 20 bird species were collected each year.

The smaller passerines had sometimes obviously, barely made the journey across the Atlantic due to unfavourable winds, and landed quite exhausted on Surtsey. This could be observed by the general appearance of the birds and demonstrated by measuring the lack of fat deposits which birds use on their oversea crossings. Such conditions were especially apparent in ^{the} case of wheatears that apparently sometimes proceed with a continuous migration flight from West Africa to Iceland. The ornithological work on Surtsev, furthermore, consisted in weighing and sexing the collected birds, as well as searching closely for any seeds that the birds might be carrying in their alimentary tract.

The greatest ornithological event, however, took place in the summer of 1970, when the first birds started nesting. These were seabirds of species common to the Westman archipelago, i.e., the fulmar, Fulmarus glacialis, and the black guillemot, Cephus grylle. The former had built a nest on a ledge 10 m above sea-level in the cliffs on the western side of the island whereas the latter had built its nest in a crevice in the lava rock on the south-west side. Both nests were successful and birds of both species have since successfully nested every year on the island. In 1971 the colonization of birds proceeded with ten to eleven of

fulmar nests and six black guillemot nests. In 1972 there were thirteen fulmar nests and possibly six to eight black guillemot nests dispersed along the rocks of the south-west coast. Both of these birds species are now breeding permanently on the island, with their colonies becoming an integral part of the island's ecosystem, although they have to obtain their food and feed their young from the nearby ocean.

The lack of food sources from the producers or primary consumers of the ecosystem still hinders colonization of landbirds to any extent, and the nesting of such birds will hardly begin to take place in the near future, except by birds such as the raven that can make use of carcasses drifting ashore on Surtsey. The population of birds that may be considered permanent on the island is still small in numbers, but as the birds have colonized the island most divisions of the plant and animal kingdom have been represented on Surtsey. Now it is only a matter of time before the colonists develop further their new community.

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