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on behalf of the Ministry of Education, Science and Culture

Nomination of Surtsey for the UNESCO World Heritage List

January 2006

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SURTSEY

for the UNESCO World Heritage List

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SURTSEY

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In the ancient Eddic poem Völuspá, the prophetess describes the birth as well as the fate of life. She tells Odin about the world tree – the ash Yggdrasil – and about life as it was created and has evolved on earth but will in the end be destroyed by fires of the giant Surt, the dark ruler of fire. Upon Ragnarök, the final destruction of the world, Surt will lead the sons of Muspel against the gods. As he enters “burning everything in his path, men plunge to hell and the heavens are split apart”*.

Völuspá	**Völuspá: The Prophecy***
52. vísa	Verse 52
Surtur fer sunnan með sviga lævi, skín af sverði sól valtíva, grjótbjörg gnata, en gífur rata, troða halir helveg, en himinn klofnar.	Surt comes from the south with his wood-eating fire, sun glints on the sword of the godly warriors. Boulders slam together, sending trolls tumbling, men tread the path to Hell and the heavens cleave.

In 1963, when volcanic fires began erupting on the seabed south of Iceland and building up a tephra cone, it was found appropriate that the resulting island should be named Surtsey, a word formed in the normal Icelandic manner of including the possessive form of a person's name in a place name: Surtsey = Surt's island (ey meaning “island” in Icelandic) = the island of Surt, the fire giant.

*Völuspá: The Prophecy. The prophecy of the Vikings – the creation of the world.
Gudrun 2001. English translation by Bernard Scudder, p. 70.

Preface

Surtsey is a scientifically unique area. It offers an outstanding example of a virgin, volcanic island that is being actively created and shaped by geological, geomorphological and ecological processes. The present nomination document proposes that the Surtsey Nature Reserve, including the entire Surtsey volcano and the surrounding sea, be recognised through the award of World Heritage Site status, in particular due to its international importance for the natural sciences.

It was on 15 November 1963 that Surtsey emerged as a new volcanic island in the picturesque Vestmannaeyjar archipelago. The formation of Surtsey provided the scientific community with a unique opportunity to study the development of an oceanic volcano from its inception on the sea floor to the creation of an island, and then throughout the modification of this newly erected structure by physical and ecological processes. Since its emergence, the island of Surtsey has been strictly protected and human influence restricted to a minimum. Surtsey has thus offered a natural laboratory in geology, geomorphology and ecology which has provided invaluable information on the creation and history of the Earth and its biosphere.

Preparations for this nomination have involved local and national authorities and various interested parties. Commissioned by the Icelandic World Heritage Committee, the Icelandic Institute of Natural History has compiled this nomination document with the assistance and advice of many people and institutions.

Our vision is that a World Heritage Site status will further the long-term conservation of Surtsey as a pristine nature reserve. Thus we feel it is both a delight and an honour to recommend this nomination to the World Heritage Committee of UNESCO.

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This report has been commissioned by the Icelandic World Heritage Committee on behalf of the Ministry for Education, Science and Culture and the Ministry for the Environment. However, the editors and authors are responsible for all the presented results and conclusions.

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1

Identification of the property

1.a Country
Iceland

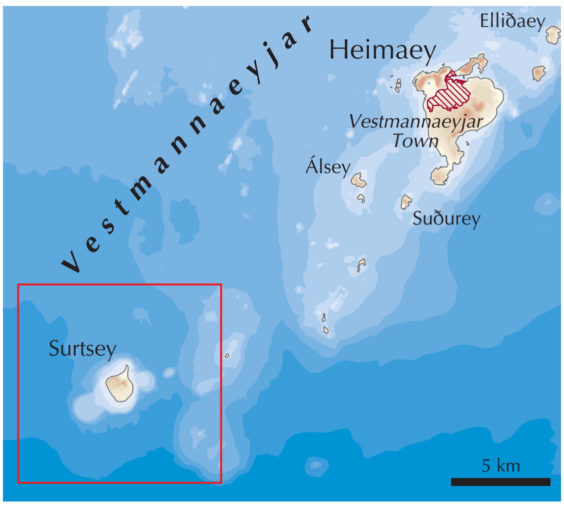
1.b State, province or region
Municipality of Vestmannaeyjar

1.c Name of property
Surtsey Nature Reserve

1.d Geographical coordinates to the nearest second
The nominated area is bounded by latitudes 63°16´N and 63°20´N and longitudes 20°31´W and 20°41´W.

1.e Maps and plans showing the boundaries of the nominated property and buffer zone
Figure 1.1 is a map showing the location and boundaries of the nominated area.

1.f Area of nominated property and proposed buffer zone
The protected nature reserve which is being nominated for inclusion in the World Heritage List (Fig. 1.1, black line), has a total area of 65.6 km². It is divided into two protection regimes: a core area of 33.7 km² (Fig. 1.1, red line), encompassing the aerial (1.4 km²) and submerged (13.2 km²) parts of the Surtsey volcano where fisheries using towed bottom fishing gear are prohibited, and a buffer zone of 31.9 km² allowing such fisheries (Chapter 7b). However, a separate temporary ban on towed bottom fishing gear applies to some 12.7 km² of the buffer zone (Fig 1.1, yellow line).



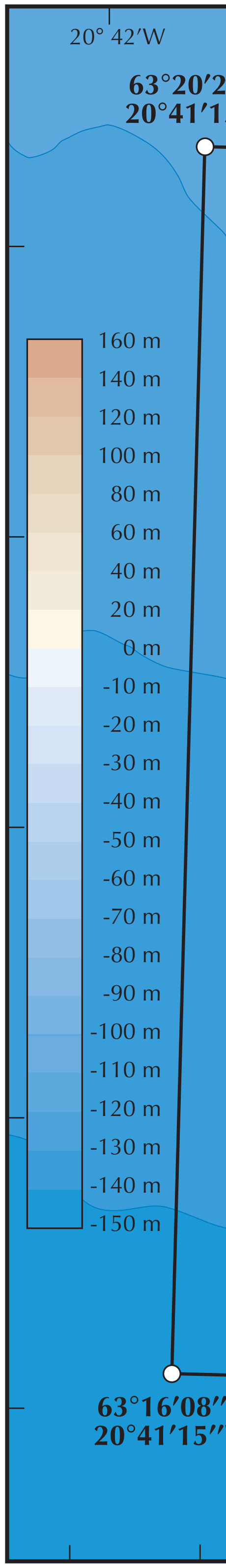
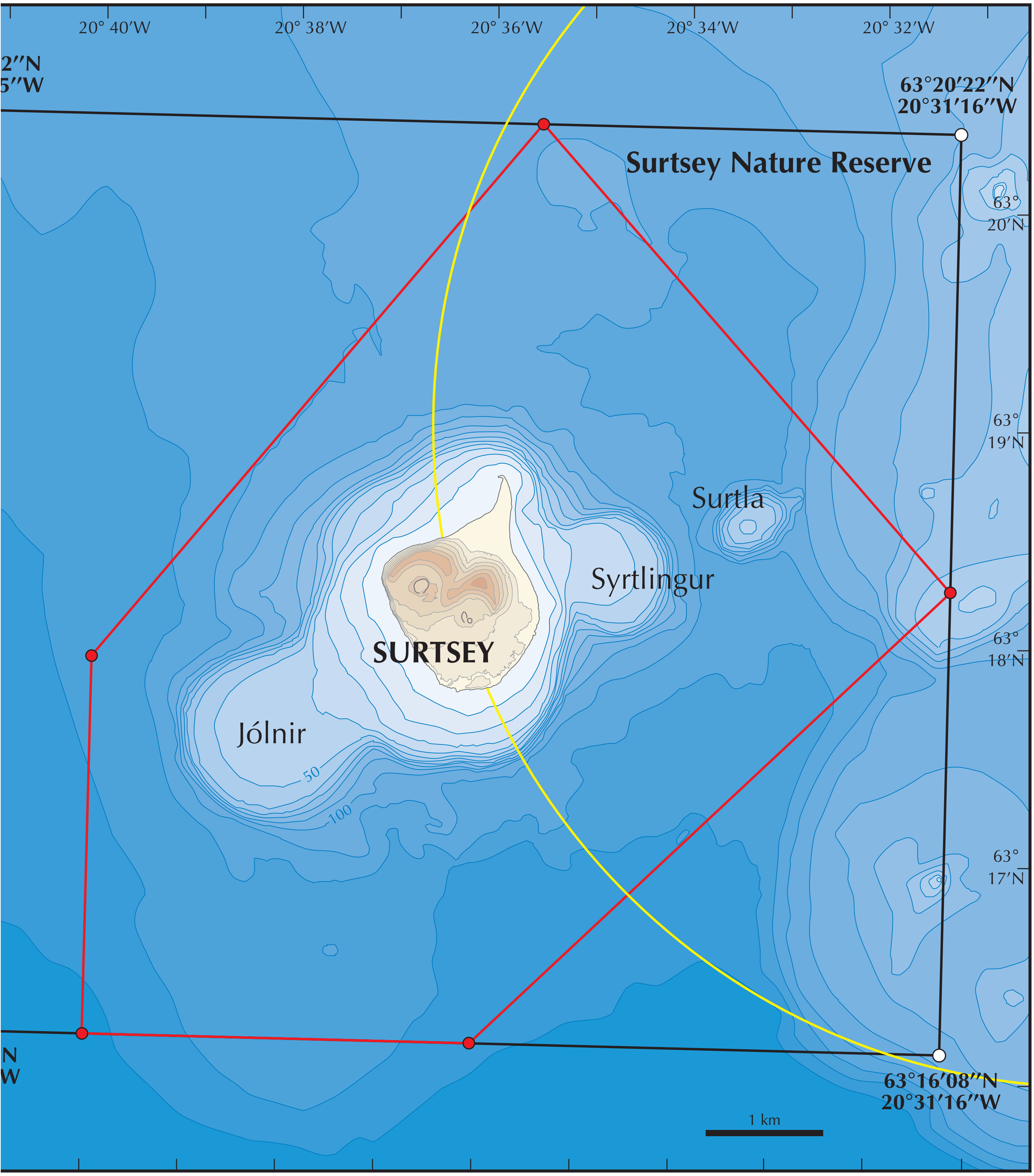


Fig. 1.1. Map of the Surtsey Nature Reserve, showing boundaries of the nominated area. Smaller figures show the location of the nominated area within the Vestmannaeyjar archipelago, the location of Vestmannaeyjar off Iceland's south coast, and the location of Iceland in the northern hemisphere.


20° 40′W
20° 38′W
20° 36′W
20° 34′W
20° 32′W
2″N
5″W
63°20′22″N
20°31′16″W
Surtsey Nature Reserve
63°
20′N
63°
19′N
Surtla
Syrtlingur
SURTSEY
63°
18′N
Jólnir
50
100
63°
17′N
N
W
63°16′08″N
20°31′16″W
1 km

Aerial photograph of Surtsey, August 12th, 2004.
(With permission from: Loftmyndir Ltd.).

2 Description

2.a Description of property

Iceland – geological overview

Iceland is an integral part of the Mid-Atlantic Ridge and also its largest supramarine segment (Fig. 2.1) with a landmass of 103,000 km^2. Sometimes described as a hot spot above a mantle plume, Iceland is built almost exclusively of volcanic rock, predominantly basalts, while sediments constitute about 10% of the island's overall volume. Since the land has been built up during the last 16 million years, it is geologically speaking a young country. Iceland's rocks can be divided into four geological formations: the Late Tertiary Basalt Formation, the Late Pliocene and Early Pleistocene Basalt Formation, the Late Pleistocene *Móberg* Formation, and the Holocene Formation (Fig. 2.2).

The crest of the Mid-Atlantic Ridge marks the boundary between the North American and Eurasian tectonic plates. These two plates move towards the west-northwest and east-southeast respectively, with an average spreading rate that is calculated to be ≤1 cm/yr in each direction in the region of Iceland. Because the centre of spread, running from southwest to northeast, crosses Iceland, the island expands continuously through a process of rifting apart and accreting new crust, which stems from volcanism along the crest zone of the Mid-Atlantic Ridge.

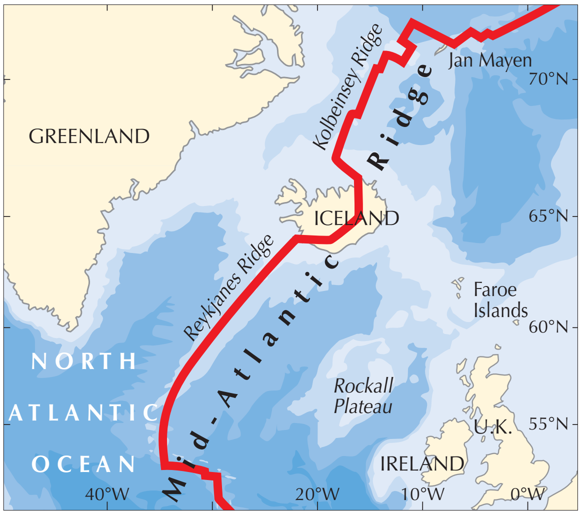


Fig. 2.1. The Mid-Atlantic Ridge in the region of Iceland, with a red line showing the boundary between the North American and Eurasian tectonic plates.

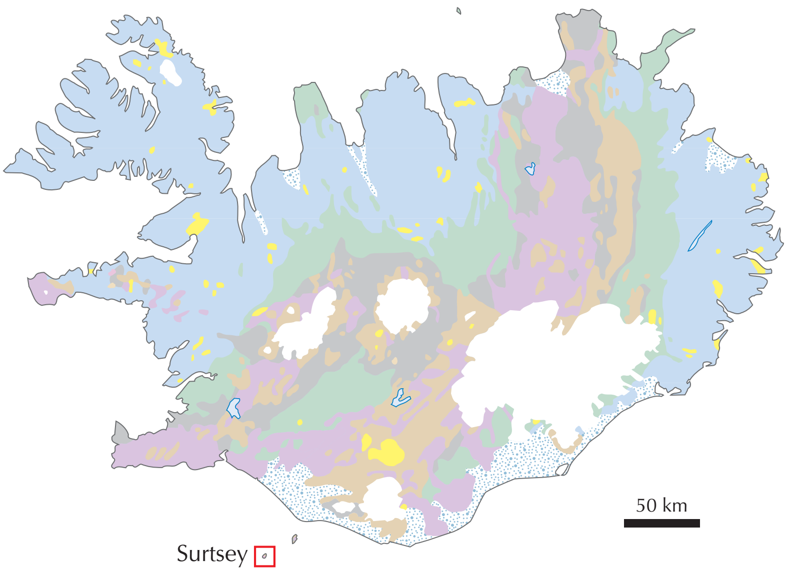


Fig. 2.2. Simplified geological map of Iceland, displaying the principal geological formations.

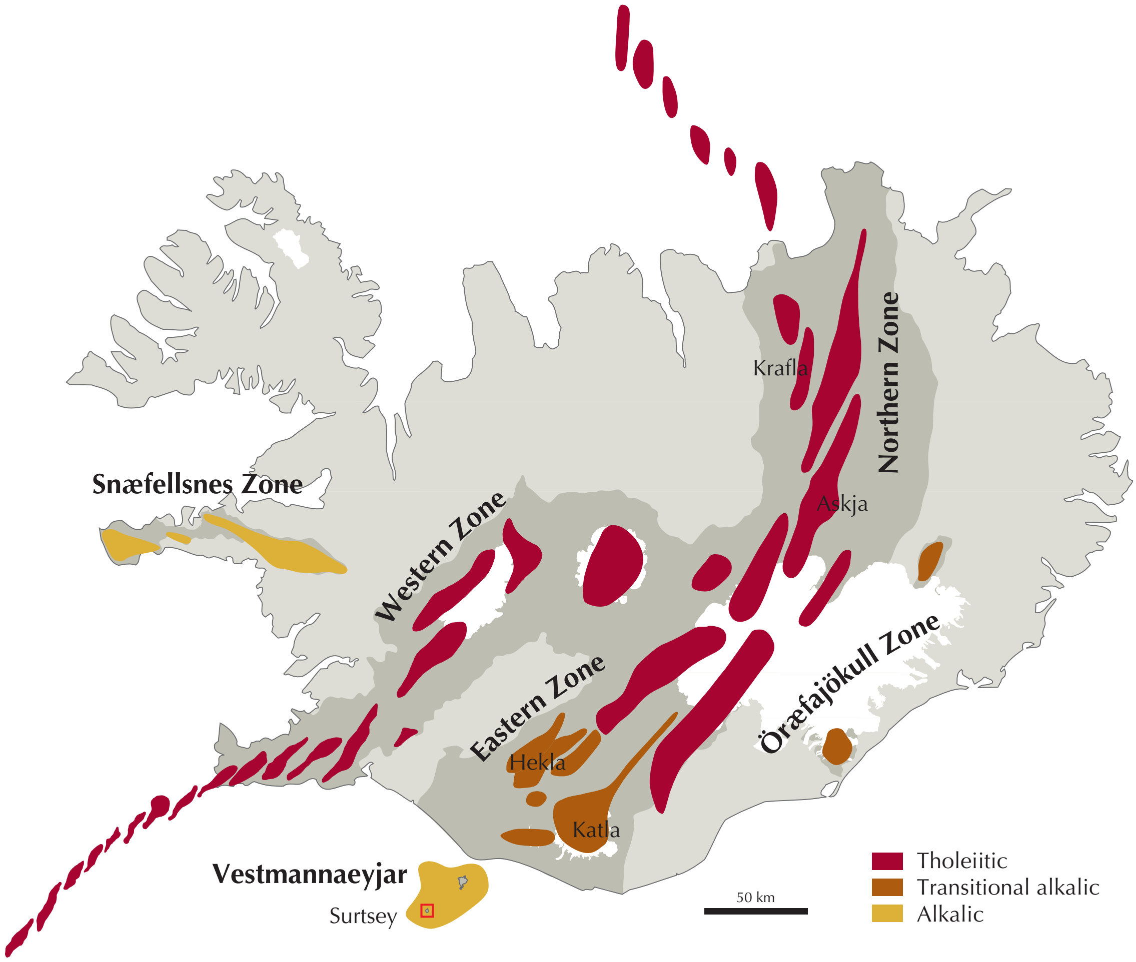


Fig. 2.3. Active volcanic systems in Iceland and on its insular shelf, grouped according to petrological criteria. The distribution of rocks from the Late Pleistocene and Holocene (dark grey) is also shown.

The volcanic zones of Iceland (Fig. 2.3), are among the most active on Earth, with an eruption occurring every three years on average. Moreover, the country's volcanic activity is associated with vigorous hydrothermal activity.

Icelandic volcano-tectonics appear to have been characterised by volcanic systems throughout the island's geological history. A volcanic system is a spatial grouping of eruption sites, including feeder dikes and possibly shallow magma chambers, that usually have in common certain structural, petrographic and geochemical characteristics within the bounds of the system. Volcanic production is generally most intense around the middle of each system, where many have developed a central volcano with the concomitant production of intermediate and acid rocks. High-temperature hydrothermal activity is often connected with the central part of each system, evidenced by steaming vents and solfataras.

In Iceland and on its insular shelf, about 44 volcanic systems have erupted at least once during the Holocene and Late Pleistocene (Fig. 2.3), the most active being the Hekla, Katla, Askja and Krafla systems. The Hekla central volcano has erupted 19 times during the country's historic period (i.e. since AD 900), most recently in the year 2000. The subglacial central volcano of Katla has during the same period erupted on average twice a century, including the most recent eruption in 1955. The latest eruption within the Askja caldera occurred in 1961, while the Krafla volcanic system produced nine small eruptions from 1975 to 1984 (Ari Trausti Guðmundsson 2001).

Vestmannaeyjar archipelago

Surtey island is a part of the the Vestmannaeyjar archipelago (Fig. 2.4), which consists of 18 islands and a number of skerries, and is situated on the insular shelf off the central south coast of Iceland. Heimaey is the largest island (13.6 km²) and the only one to be inhabited (4,200 residents). It has one town which is also called Vestmannaeyjar and the most important fishing harbour along the south coast of Iceland.

Vestmannaeyjar constitutes a separate volcanic system at the southern end of Iceland's Eastern Volcanic Zone (Fig. 2.3). This is a young system, having probably commenced activity some 100,000 years ago, and its oldest part, the Norðurklettar Formation, is exposed on the northernmost end of Heimaey. Norðurklettar Formation was built up by small volcanoes which probably erupted through an ice cap, leaving behind palagonite tuffs and tuff breccias capped by lavas. No high-temperature hydrothermal activity has been discovered at the surface in Vestmannaeyjar (Sveinn P. Jakobsson 1979).

During the Holocene (during the last 12,000 years), volcanism has remained at low intensity in the Vestmannaeyjar system. Seventeen volcanoes, of which three are on Heimaey, have been identified above sea level. These volcanoes originally rose from the sea floor in the same way as Surtsey, even at similar sea levels. The largest of the volcanoes comprise the islands of Bjarnarey, Elliðaey and Suðurey, and include

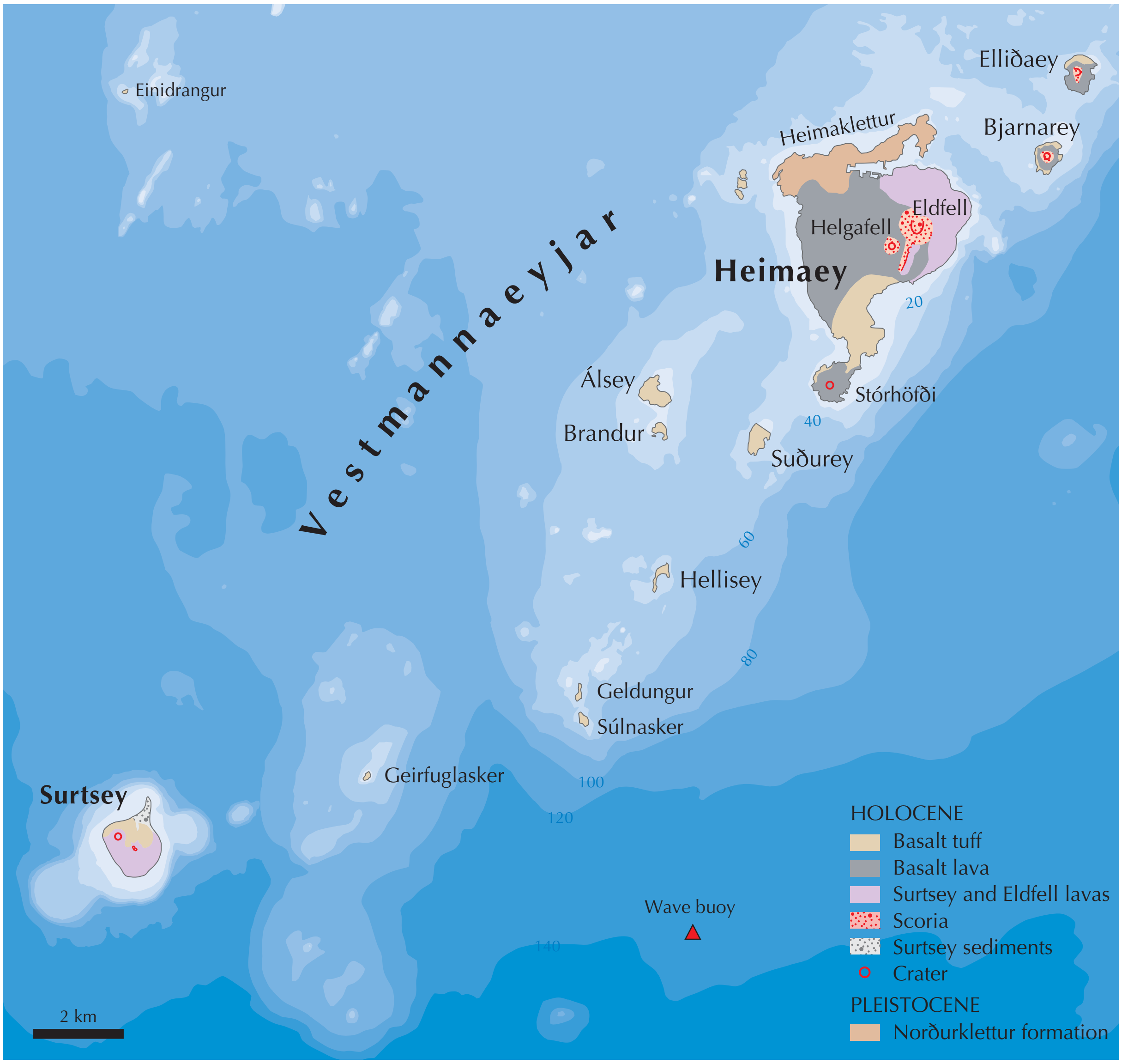


Fig. 2.4. Simplified geological map of the Vestmannaeyjar archipelago.

Stórhöfði and Sæfell-Helgafell on the island of Heimaey. Two volcanic eruptions are known with certainty in historic times: the Surtsey eruption of 1963–1967 and the 1973 Eldfell eruption on Heimaey. A small submarine eruption may have occurred on the sea floor southeast of Hellisey in 1896. Furthermore, four young submarine volcanoes have been discovered, so that altogether 24 volcanic eruptions are known to have occurred within the Vestmannaeyjar system during the Holocene (Sveinn P. Jakobsson 1979). In addition to the submarine rises produced by the Holocene eruptions, numerous hills and peaks on the sea floor (Fig. 2.4) presumably represent remnants of more than 40 Late-Pleistocene submarine volcanoes. Most of the volcanoes in the Vestmannaeyjar system are relatively small.

As a large part of the Vestmannaeyjar volcanic system is submarine, its geographical limits are difficult to delineate exactly; however, it reaches about 38 km from southwest to northeast and 29 km from northwest to southeast, covering an area of 900–1000 km^2, where the average depth of the sea is about 70 m. The volume of volcanic rock extruded within the Vestmannaeyjar volcanic system during the Holocene period has been estimated as ≥ 3.5 km^3, which is one order of magnitude less than the output of the highly active Hekla and Katla volcanic systems. Investigations on the Vestmannaeyjar shelf (Sveinn P. Jakobsson 1982; Kjartan Thors and Jóhann Helgason 1988) indicate that local submarine as well as subaerial volcanism was the source of the material building up the marine shelf and that for the most part this build-up has probably been ongoing for the last 100,000 years.

Aerial view to the southwest of the Vestmannaeyjar archipelago. Elliðaey and Bjarnarey are in the foreground, Heimaey in the middle and Surtsey in the far background (Photo: Ragnar Th. Sigurðsson 2000).

The main activity in the Vestmannaeyjar volcanic system has occurred in and around Heimaey (Fig. 2.4), which has accordingly formed a topographic high. Indeed, it has been proposed that Heimaey is evolving into a central volcano (Sveinn P. Jakobsson 1979). On the other hand, there are strong indications that Vestmannaeyjar system volcanism is episodic. The youngest Late-Pleistocene tuffs and lavas of the Norðurklettar Formation seem to have all been deposited within a short time interval. There also appears to have been a major volcanic episode 5,000–6,000 years ago, leading to the formation of Stórhöfði and Helgafell on Heimaey

Fig. 2.5. Three-dimensional model of the Surtsey volcano (oblique view from the south), prepared by the Institute of Earth Sciences, University of Iceland, based on aerial photographs from 2004 (Loftmyndir Ltd.) and depth soundings of the seabed from 2000 (Hydrographic Department).

and of the islands of Bjarnarey and Elliðaey northeast of Heimaey. The most recent volcanic episode may have started with the reported submarine eruption in 1896, followed by the Surtsey eruption of 1963–1967 and the Eldfell eruption in 1973.

In contrast to the Surtsey eruption, which had insignificant effect on the residents of Heimaey, the Eldfell eruption on their island in January to June 1973 had disastrous effects (Williams and Moore 1983). A 3-km-long eruption fissure opened up at the eastern outskirts of town; 350 houses (30% of the total) were destroyed by lava or tephra and further 400 were damaged. Miraculously only one life was lost, as all the islanders were evacuated from the island within hours. About two-thirds of the residents returned in following summer, or about 3500 out of 5300 pre-eruption inhabitants. The Eldfell eruption is considered to be one of the most destructive volcanic eruptions in the history of Iceland.

Surtsey

Topography

The Surtsey volcano, which belongs to the Vestmannaeyjar volcanic system, rose from the sea floor in a volcanic eruption occurring from 1963 to 1967. The eruption history of Surtsey volcano is described in Chapter 2b. At the end of the eruption in 1967, the island of Surtsey had attained a surface area of 2.65 km^2 and the total volume of erupted material was estimated to be 1.1 km^3, about 70% of which was tephra and 30% lava. The island is the subaerial segment of the complete Surtsey volcano, which forms a mainly submarine ridge approximately 5.8 km long and oriented southwest-northeast. Measured from northwest to southeast, the volcano's maximum width is 2.9 km and its base area encompasses some 14 km^2 (Fig. 2.5). The Surtsey volcano has changed considerably since the eruption ended in 1967, and the following topographical and geological description is based mainly on data collected in the summer of 2004. The description of bottom topography is based on

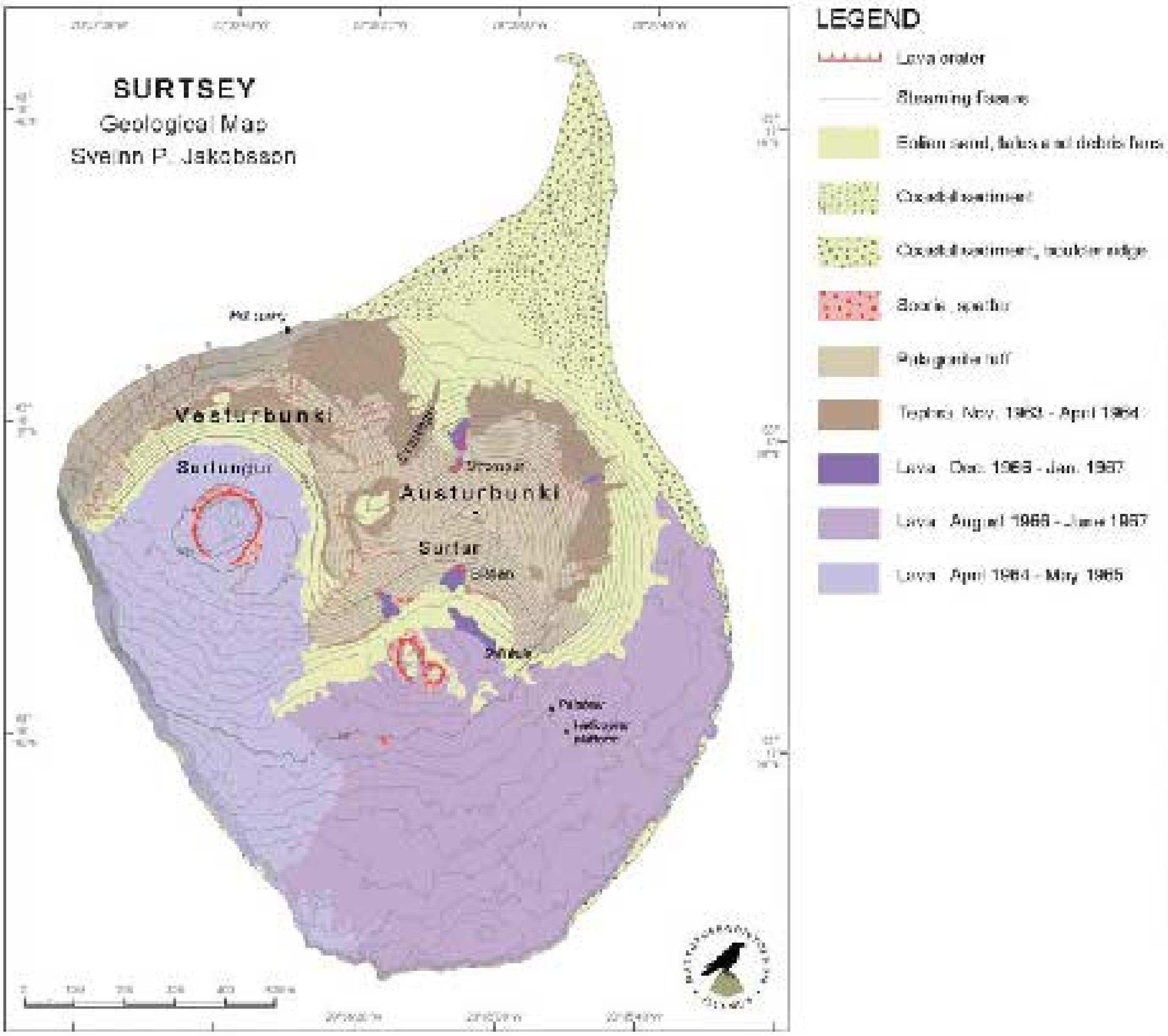


Fig. 2.6. Geological map of Surtsey. Topography is based on aerial photographs from August 2004. See also enclosed map in the scale of 1:5000.

depth measurements by the Icelandic Maritime Administration in the summer of 2000.

Surtsey has a surface area of 1.41km², a maximum width from west to east of 1.33 km and a maximum length from north to south of 1.80 km (Fig. 2.6; see also enclosed map). It is the second largest island of the Vestmannaeyjar group, followed by Elliðaey (0.46 km²) and Bjarnarey (0.33 km²). Although the highest elevation on Surtsey is only 155 m, the sea depth prior to the eruption was about 130 m, so that the true height of the volcano is 285 m.

Surtsey's prominent topographical features are two crescent-shaped cones composed of tephra and palagonite tuff, along with a lava field that caps the southern half of the island. Rising to an elevation of 155 m, the eastern cone, Austurbunki (“the East Mound”), is marked by several small lava craters and fissures. The western cone, Vesturbunki (“the West Mound”), whose height is 141 m, has large slump scars due to marine abrasion on its western side, where a 135-m-high sea cliff has formed. From the tuff cones, the main lava field forms a shield gently dipping to the south and east. Transported coastal sediments have mainly been deposited at the north end of the island, constructing a broad spit.

The shape of Surtsey is constantly modified by the harsh weather conditions which prevail in the sea south of Iceland, particularly during winter.

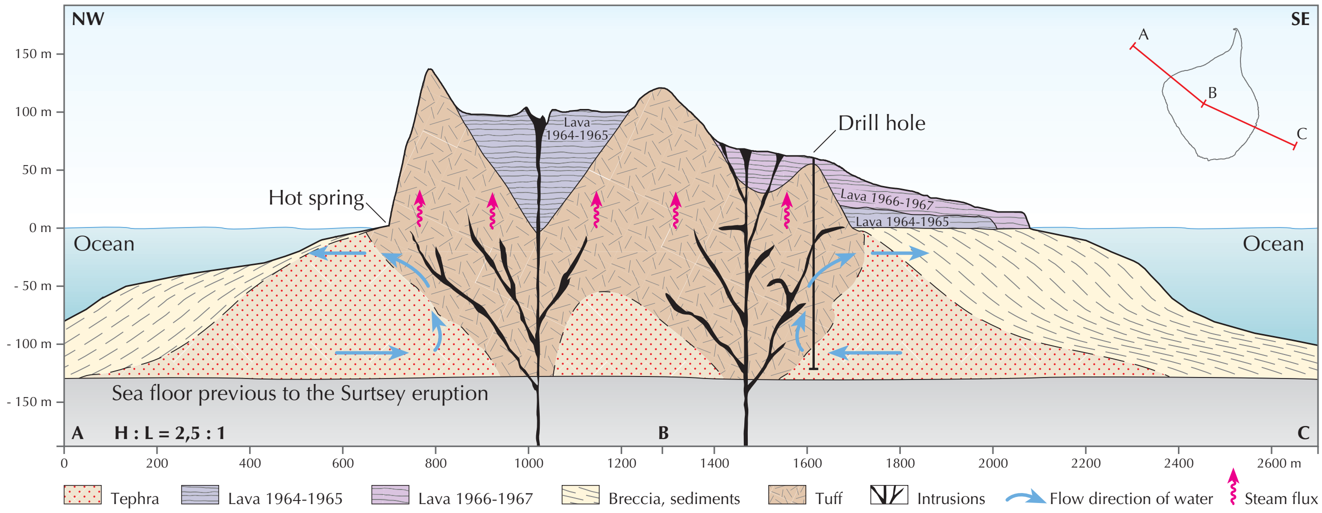


Fig. 2.7. NW-SE profile through the Surtsey volcano.

Heavy sea waves erode the coast and produce coastal sediments. Being easily eroded and transported by the wind, loose, unconsolidated tephra has collected as aeolian deposits along the flanks of the two cones, as well as on the lava field. Wind deflation is conspicuous in the island's tuff, where it has at places created potholes up to 0.5 m deep and 1.5 m in diameter.

Running water is rarely observed on the surface of the tephra and lava because of their high porosity, although small, temporary streams do appear on the tuff surface after exceptionally heavy precipitation. These temporary streams have eroded the unconsolidated tephra which in most places surrounds the tuff and built fans at the base of slopes, so that mudflow channels have developed at several points on the tuff cone slopes. On the northern slopes of Vesturbunki and Austurbunki, these mudflow channels are usually 0.5–2 m wide and reach down to the foot of the slope. On the inner slope of Austurbunki, smaller mudflow channels can be observed that have solidified into rock since their original formation in unconsolidated tephra.

Apart from Surtsey, eruptions occurred on the sea floor at three sites, concurrent with the Surtsey eruption. About 2.5 km north-northeast of Surtsey, a submarine tephra ridge was built up between December 1963 and January 1964. Recent depth measurements indicate its length as 0.9 km and its width as 0.6 km, and it rises 60 m above the sea floor (Fig. 2.6). At a distance of 0.6 km to the east-northeast of Surtsey, explosive activity formed the island of Syrtlingur in 1965. Today, however, only a submarine platform remains, measuring 1.2 km in diameter and rising 70–80 m above the sea floor. In 1965–1966 yet another island, called Jólnir, was formed by explosive activity 1 km southwest of Surtsey. Today it is only represented by a seamount with a diameter of 1.7 km and an elevation of 60–70 m above the sea floor (Norrman and Erlingsson 1992).

Geology

The surface of Surtsey has been mapped in detail, using conventional methods. Furthermore, a 181 m deep research hole was drilled in 1979 at the southeast corner of Austurbunki in order to investigate the subsurface constitution and structure of the island. Surtsey, designated as a submarine tuya (Sigurður Þórarinsson 1966; Guðmundur Kjartansson 1966), has now become the best-studied volcano in Iceland. While the term tuya was originally restricted to subglacial volcanoes, it has since been extended to include volcanoes that have erupted into lakes or shallow seawater. Surtsey is considered to be the world's only well-preserved submarine tuya. The two primary geological units formed during the Surtsey eruption are tephra and lava. Basal pillow lava, an important part of most subglacial tuyas, apparently did not develop in Surtsey because of the shallow water depth (Sveinn P. Jakobsson and Moore 1986). The eruptive products at Surtsey are composed of alkali basalt with phenocrysts of

View to the northwest over the crater Surtungur. (Photo: Daníel Bergmann 2003).

olivine, plagioclase and chromian spinel. In addition, three secondary geological units are found there: palagonite tuff, aeolian and talus sediments, and coastal sediments (Fig. 2.6).

Tephra

During the explosive submarine phase of the Surtsey eruption, from November 1963 to April 1964, basalt tephra (volcanic ash) was produced through the quenching of hot magma by cold sea water. The resulting tephra formed two crescent-shaped cones which merged, and today cover an area of 0.34 km^2. The cones are built up of tephra layers which to a considerable extent have consolidated into tuff due to posteruptive hydrothermal activity. Geologists call craters of this type tephra or tuff rings, depending on which material dominates. The eastern tuff cone, named Surtur or Austurbunki, has a crest-width of 0.43 km, and the western tuff cone, Surtungur or Vesturbunki has a crest-width of 0.52 km. On the scale of other Icelandic tuff or tephra craters, the Surtsey tuff craters are medium-sized.

Characterised by poor sorting and varying grain size, Surtsey tephra ranges in its constituents from silt to boulders (Lorenz 1974), although it is mainly made up of fine glass shards less than 2 mm in diameter, along with mineral phenocrysts and small rock fragments. The tephra deposited above sea level forms finely-bedded layers and is poorly sorted, contrasting to the tephra below sea level, which is more chaotic in structure and whose grains sometimes demonstrate considerable size sorting. The porosity of the tephra layers above sea level, must rate as very high, or 45–50% by volume.

Surtsey has come to be the world type locality for Surtseyan tephra (Walker and Croasdale 1972; Walker 1973), i.e. tephra produced by hydromagmatic explosions in shallow water. The island is also an important site for accretionary lapilli (Sveinn P. Jakobsson and Moore 1982), whose individual pellets there reach the exceptional diameter of 3.5 cm. Also, Surtsey was one of the first localities in the world where vesiculated tuff was noted and described, i.e. tuff that contains independent vesicles between particles, where steam was trapped while the original tephra was being deposited (Lorenz 1974).

Lava

The Surtsey eruption evolved from an explosive phase into an effusive phase at the western crater (Surtungur) in April 1964, when the island was large enough to isolate that vent from inflowing seawater. Altogether, seven Surtsey craters and crater fissures emitted lava between April 1964 and June 1967 (Fig. 2.6). The first major effusive phase (1964–1965) produced a lava shield extending 100 m above sea level and containing, when finished, a total volume of 0.3 km^3, while the second phase (1966–1967) produced a 70-m-high lava shield with a volume of 0.1 km^3. Both of these shields consist of two structural units: an inner lava cone and an outer lava apron (Thorvaldur Thordarson 2000). Together they form a lava field that slopes gently to the south and east. Added to this are five small lava flows on the slopes of Austurbunki. Today the lavas cover an area of 0.72 km^2.

When lava flows into water it brecciates and gradually builds up a submarine delta in front of the shore. Such a delta is foreset-bedded and consists of the products of the quench-fragmentation of molten lava and the disintegration of subaerial lava flows. At Surtsey the final layers in the western lava crater have achieved a total thickness of 230 m, resting on a 130-m-thick brecciated foundation which lies below sea level.

Due to heavy marine abrasion, high lava cliffs have formed on Surtsey and now tower a height of 80 m over the southwest shoreline. These cliffs

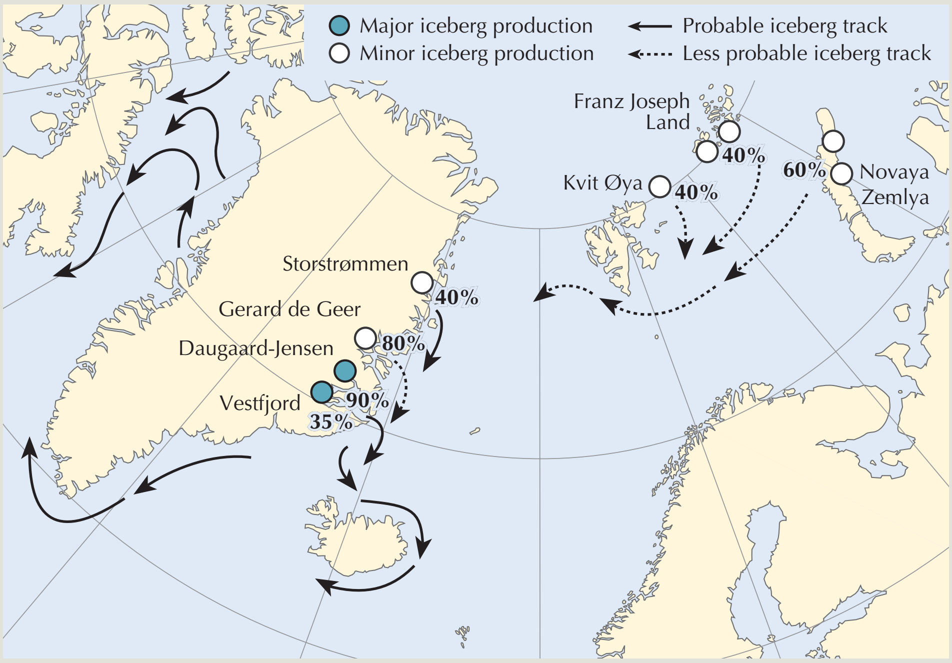
Typical ropy lava surface at the southern coast of Surtsey. (Photo: Borgþór Magnússon 2005).

provide excellent outcrops for viewing the internal structure of the subaerial lava shield, which was constructed by multiple lava flows whose thickness varies but averages 1–2 m. The morphology of the lava surface is very interesting, particularly through the possibility of referring to the modifications it underwent, according to the detailed contemporary descriptions by Sigurður Þórarinsson (1966, 1967, 1968) and Þorleifur Einarsson (1966). The Surtsey lava flows are mostly smooth *pahoehoe* flows, even if rugged *aa* flows are also evidenced, mainly in two areas in the lava produced from 1966 to 1967.

Being basaltic and having a low viscosity, the Surtsey lavas tended to flow in tubes or closed trenches, especially from Surtungur, the western lava crater. Many of the lava tubes were left hollow. Tumulus structures are common, with observations showing that tumuli form when the lava crust becomes inflated above a wide pool of molten lava. Surtsey also has hornitos at several locations, and one small pit crater remains southwest of the Surtungur where the roof of a large lava tube collapsed (Fig. 2.6).

The geometry and profile of the subaerial segments of the Surtsey shields are strikingly similar to those of other monogenetic lava shields in Iceland and everywhere else, which permits the study of the effusive activity at Surtsey as an analogue for establishing a conceptual model of shield volcanoes in general.

Possible origin of exotic xenoliths found in the Surtsey tephra



Possible origin of the exotic xenoliths from Surtsey. Numbers refer to the proportion of the exotic xenoliths that match formations presented on geological bedrock maps of each area. Several factors combine to make Daugaard-Jensen glacier in East Greenland the most probable origin of the exotic xenoliths. Most of the samples from Surtsey can be traced to its surrounding area. (From Reynir Fjalar Reynisson 2006).

Typical samples of the exotic xenoliths from Surtsey, including granite, gneiss, quartzite and dolomite. (Photo: Kristján Jónasson 2006).

Rock fragments of varying size and exotic origin are not uncommon in the Surtsey tephra. Since these fragments are quite diverse, they have been classified into five main groups, each offering valuable information on a specific geological issue. A conspicuous example of these groups is fossiliferous bits which the submarine explosions blasted upwards from the site's former sea floor. Another group, whose fragments include granite, gneiss, quartzite, dolomite and schist, has attracted special attention, since such rock types cannot be of local origin. It has been suggested that icebergs transported them from East Greenland to the environs of Vestmannaeyjar, probably for the most part during the early Holocene. According to this theory, icebergs containing terrestrial debris drifted with ocean currents from their place of origin to the Vestmannaeyjar vicinity. As the icebergs melted there in the warmer ocean, the rock debris they had brought from a far-off land sank to the seabed. While the Surtsey eruption was in its explosive submarine phases, this debris originating from icebergs was blasted into the atmosphere, along with pieces of the uppermost sea floor. As the blasted material settled, it mixed with the tephra in the rock compositions found today (Fig. 2.6). (Reynir Fjalar Reynisson 2006).

Geological definitions

Accretionary lapilli: Spheroidal pellets consisting of cemented or consolidated tephra and measuring generally between 1 mm and 1 cm in diameter. Formed in the explosion column by the accretion of wet particles around a nucleus which is usually a rock fragment.

Alkali basalt: A silica-undersaturated basalt, uncommon in Iceland.

Breccia: A coarse-grained rock composed of angular rock fragments.

Encrustation: A mineral crust formed on a rock surface.

Holocene: The youngest geological epoch, representing the last 11,500 years of the geological record.

Hornito: A topographically insignificant mound or rise of spatter from around an opening in the roof of an underlying lava tube.

Hydromagmatic eruption: An explosive volcanic eruption caused by magma interacting with ground water, surface water or sea water.

Magma: Molten rock material that contains suspended crystals (phenocrysts) and is generated within the upper mantle or crust. Upon extrusion in Surtsey, the temperature of the magma was 1,155° –1,180° C.

Móberg: An Icelandic term for brownish, consolidated tephra, of basaltic or intermediate composition.

Móberg Formation: A chronostratigraphical term spanning all Icelandic deposits from the Late Pleistocene, i.e. between 0.78 and 0.01 million years ago.

Palagonite: An altered, hydrated, basaltic glass, of brown or yellow colour. The term is related to the alteration process, called palagonitisation.

Phenocryst: A relatively large, conspicuous crystal in a fine-grained or glassy groundmass.

Pillow lava: Lava displaying pillow structure and formed in a subaqueous environment.

Plate tectonics: A theory of global tectonics according to which the lithosphere is divided into a number of plates; these undergo horizontal movements leading to seismic and volcanic activity along plate boundaries.

Pleistocene: The geological epoch just previous to the Holocene, starting 1.8 million years ago and ending 11,500 years ago.

Silt: Sediment finer-grained than sand but coarser than clay.

Solifluction: Slow, viscous, downslope flow of waterlogged surface material.

Spit: A small point or low tongue or narrow embarkment of land, commonly consisting of sand or gravel deposited by longshore transport.

Talus: Coarse rock fragments derived from a cliff and lying at its base.

Tephra: Unconsolidated rock particles expelled through volcanic vents or produced by steam explosions. Classified according to its particle size, tephra consists mainly of basaltic glass.

Tuff: Tuff is cemented or consolidated tephra, while tuff breccia contains coarse fragments of basalt.

Tumulus: Isolated cupola-shaped mound that protrudes from a lava surface and is typically 1.5–3 m high and 5–15 m in diameter.

Tuya: A relatively flat-topped volcano formed by an eruption into water thawed from an ice cap, or into a lake or seawater. Also called a table mountain, a tuya is mainly composed of tephra and is usually capped by subaerial lava.

Vesiculated tuff: Tuff that contains vesicles left by steam which was trapped between particles during deposition of the original tephra.

Scientists measuring temperature at a steaming fissure on the western crest of Surtungur. (Photo: Sveinn P. Jakobsson 1997).

Lava caves

Surtsey has four emptied, subhorizontal lava caves which have been mapped; the longest such cave measures 181 m. Emptied, near vertical lava feeder dikes to craters can be described as a second type of cave on the island. Five caves of this type have been mapped, the largest of which extends about 20 m down. Stalactites and stalagmites of lava are common in the lava caves and reach a length of 20 cm. The occurrence of lava caves and caverns in the comparatively small lava field on Surtsey exceeds what has been observed in other Icelandic lava fields (Björn Hróarsson 1990).

Encrustations

Fumarolic gases in the cooling lavas resulted in colourful volcanogenic mineral encrustations that are especially abundant close to craters. Some of these encrustations, being water soluble, quickly disappeared, while others were easily affected by general weathering processes. In some of the deeper lava caves, however, abundant volcanogenic encrustations are still present (Sveinn P. Jakobsson et al. 1992). Another type of encrustation is of the evaporitic sort. Not only does down-seeping precipitation on Surtsey contain a high proportion of ocean spray, but seawater seeping into the island presumably boils where it comes into contact with hot intrusions at sea level. Such conditions facilitate the formation of quite exceptional encrustations, whose evaporitic specimens have for instance formed stalactites reaching below cave roofs as far as 45 cm. Altogether, seventeen mineral species have been identified (Table 2.1).

I. Formed by encrustation upon the cooling and degassing of lava
Sulphur S
Halite NaCl
Fluorite CaF_2
Carnallite $KMgCl_3 \cdot 6H_2O$
Ralstonite $Na_XMg_XAl_{2-X}(F,OH)_6 \cdot H_2O$
Opal-A $SiO_2 \cdot nH_2O$
Calcite $CaCO_3$
Thenardite Na_2SO_4
Aphthitalite $(K,Na)_3Na(SO_4)_2$
Glauberite $Na_2Ca(SO_4)_2$
Anhydrite $CaSO_4$
Galeite $Na_{15}(SO_4)5F_4Cl$
Kieserite $MgSO_4 \cdot H_2O$
Blodite $Na_2Mg(SO_4)_2 \cdot 4H_2O$
Gypsum $CaSO_4 \cdot 2H_2O$
Loweite $Na_{12}Mg_7(SO_4)_{13} \cdot 15H_2O$
Kainite $KMg(SO_4)Cl \cdot 3H_2O$
New World mineral $Na_2Ca_5(SO_4)_6 \cdot 3H_2O$ (JCPDS 35-137)
II. Formed in the hydrothermal system as alteration products of basalt tephra
Opal-A $SiO_2 \cdot nH_2O$
Calcite $CaCO_3$
Anhydrite $CaSO_4$
Gypsum $CaSO_4 \cdot 2H_2O$
Tobermorite $Ca_5Si_6O_{16}(OH)_2 \cdot 4H_2O$
Xonotlite $Ca_6Si_6O_{17} \cdot (OH)_2$
Nontronite Na,K,Ca; Al,Mg,Fe-silicate
Analcime $NaAlSi_2O_6 \cdot H_2O$
Phillipsite $(K,Na,Ca)_{1-2}(Si,Al)_8O_{16} \cdot 6H_2O$
Chabazite $CaAl_2Si_4O_{12} \cdot 6H_2O$

Table 2.1. Secondary minerals formed at Surtsey.

Hydrothermal anomaly

In the spring of 1967, a mild hydrothermal anomaly was discovered at the surface in Austurbunki. The extent of this anomaly is clearly related to how the lava craters are distributed (Friedman and Williams 1970). Although there has been a postvolcanic decline in thermal flux, vapour emissions still remain visible from numerous open fissures in the tuff. In 2002 a small hot spring with temperatures at 80°C was discovered at the western shore of Surtungur (Figs. 2.6 and 2.7).

The drill hole on Surtsey provided important insights into the character of the hydrothermal system in the volcano. Figure 2.7 is a geological cross-section of Surtsey from northwest to south-east, based on the documented sequence of eruption events and on information from the drill hole. These data strongly suggest that the heat in the hydrothermal system was provided by intrusions which formed both below and above sea level from 1965 to 1966 at Vesturbunki, and from December 1966 to January 1967 at Austurbunki, in conjunction with lava extrusions in these areas (Sveinn P. Jakobsson 1978; Valgarður Stefánsson et al. 1985).

Because of the high porosity of Surtsey formations, any water at sea level inside Surtsey is presumed to be boiling, which leads to vapour dominating the hydrothermal system above sea level and to temperatures of around 100° C prevailing in the porous tephra pile (Friedman et al. 1976). Below sea level, on the other hand, temperatures of several hundred degrees C may occur, especially close to the inferred intrusions.

Palagonite tuff

The basalt tephra has been observed to alter rapidly within the hydrothermal portions of Surtsey, concluding with consolidation of the tephra into palagonite tuff. In 2004 the tuff area covered 0.24 km^2, and some 85% of the volume of the tephra cones above sea level is estimated to have changed into hard palagonite tuff. During the alteration process, the original glass shards in the tephra are chemically modified, devitrified and hydrated to produce palagonite. This process is called palagonitisation and had not previously been monitored happening in nature (Sveinn P. Jakobsson 1972; 1978). During the process, a number of chemical elements are released from the original glass in the tephra to form an array of new secondary minerals which eventually fill the voids in the rock and at the same time cements its particles together (Sveinn P. Jakobsson and Moore 1986). Ten types of minor secondary minerals are found in the palagonite tuff (Table 2.1).

The tuff sea cliff on the west coast is oxidised (red colour) by the overlaying lava. (Photo: Daníel Bergmann 2003).

A further aspect to note is that signs of bacterial activity have been observed in many tuff samples from Surtsey (Thorseth et al. 1992; Sveinn P. Jakobsson 1996), and it appears possible that bacteria contribute to altering the tephra there.

The transformation of tephra to tuff has an important implication for the future of Surtsey, since tuff has proved itself to be much more resistant to marine abrasion than tephra and even than lava. Through the formation of tuff, Surtsey has been ensured a longer life.

The tuff sea cliffs on the northwestern coast are up to 130 m high and have changed little since 1980. (Photo Sveinn P. Jakobsson 1982).

Sediments

The ferocity of wave action in the sea surrounding Surtsey has come as a surprise to geologists. Coastal erosion has been rapid, modifying the coastline markedly from year to year, above all during winter storms. Thus coastal sediments (Fig. 2.6), consisting mainly of boulders and cobbles derived from the break-up of lava (Norrman 1980; Calles et al. 1982), now covers an area of 0.15 km^2. Most of the lava shore terrace has been eroded by longshore drift towards the north, and the boulders, among which the largest are about 1.5 m in diameter, have mainly been deposited in the northern spit. Partly covered with sand originating in the tephra and tuff of the two cones, the northern spit also has overflow channels where stranded driftwood indicates the flooding on the spit every winter. Coastal material is lost downhill, probably in intermittent slump motions, to collect and form the 130-m-deep submarine slope of Surtsey.

Surtsey presents conspicuous aeolian deposits, whose source material is mainly tephra. These wind-driven deposits can be divided into two groups: firstly, the sand dunes and ripples capping the slopes of the tephra and tuff cones and, secondly, sand blowing onto and covering the lava field (Calles et al. 1982). The aeolian deposits are characterised by considerably better

The northern spit is made up of boulders, cobbles and sand. (Photo: Karl Gunnarsson 1998).

Erosion of tephra by temporary streams of water at the northern side of Austurbunki. (Photo: Sigurður H. Magnússon 2005).

sorting than the original tephra, with the dominant grain sizes belonging to the sand and silt fractions. The aeolian deposits (>0.5 m thick) now cover an area of 0.20 km^2.

Mud flow and talus deposits appear on the slopes of the two tephra and tuff cones, mainly at the north sides. This material, which has been transported by the force of gravity and running water, is characterised by poor sorting. In addition to this, some solifluction material is found on the northern sides of the cones.

The climate

Automatic meteorological observations were conducted at Surtsey over a two-month period in the late autumn and early winter of 1996. The observation station, which was at an exposed location 154 m above sea level, gave results strongly indicating that the Surtsey weather conditions and those 19 km to the northeast, at Stórhöfði lighthouse on Heimaey, are very similar. The Stórhöfði station is also at a very exposed location, standing 118 m above sea level, and has kept a continuous record of observations since 1921. During the two-month period the average temperature difference was less than 0.1° C, although the wind speed at Surtsey measured higher than at Stórhöfði during the same period. All climatological references below refer to the Stórhöfði station, unless otherwise indicated.

The maritime climate of Surtsey is characterised by relatively warm winters and cool summers. While the average monthly sea surface temperature is higher than the air temperature in every month of the year, the average difference in the winter months exceeds 4° C. On individual days in any season, though especially in the summer, the sea can become colder than the air – circumstances that commonly cause fog or extremely low clouds. All the winter months (December to March) have average temperatures between 1.5 and 2.0° C, whereas the warmest months at Stórhöfði, slightly higher than sea level, are July and August, whose average temperatures lie close to or just below 10° C (Fig. 2.8). The annual temperature range (difference between the warmest and coldest months) is thus only about 8.5° C, compared with the range in annual sea surface temperatures of about 5° C. On average, the minimum temperature drops below 0° C on 80 days of the year; however, since the maximum exceeds 0° C on most of those days, round-the-clock freezing is only experienced for 18 days per year, on average. The frost-free period lasts on average for 5 to 7 months; during the last 50 years, the longest frost-free period lasted 8 months and the shortest about 15 weeks. Maximum temperatures in excess of 20° C are quite rare; Stórhöfði has experienced only 2 such days during the last 85 years. Frost below -15° C is also extremely rare.

Stórhöfði receives ample precipitation, totalling annually about 1600 mm. Whereas June is the driest month of the year (93 mm), October comes out on average as the wettest month (156 mm), though in fact the entire fall and winter period from August to March resembles October (Fig. 2.8). Snowfall is rather slight; in fact, its sum (60 mm) comprises only around 4% of the total annual precipitation. A mixture of snow and rain falls frequently, resulting in approximately another 30% of the overall precipitation, while the remaining 66% falls as rain. During the summer, there is no snowfall. Humidity is generally high, with frequent overcast and low-cloud conditions.

Winds are strong at the nearby Stórhöfði lighthouse, where on over 130 days per year the 10-minute average exceeds 20 m/s at least once, and a sustained 10-minute hurricane force (>32.7 m/s) is exceeded on an average of 15 days per year (Fig. 2.8). Concurrent measurements at Surtsey and Stórhöfði indicate that the ridge wind at Surtsey is even stronger than at Stórhöfði; presumably, however, Surtsey's lower-level winds are considerably less violent. In any case, the sea state is often highly agitated.

Most of the weather systems affecting Surtsey arise out of the west (SW to NW). However, the westerlies aloft are usually undercut by shallow air masses from the northeast, so for most of the year easterly winds prevail in the area and are reinforced by the barrier of the South Iceland glaciers (Fig. 2.9).

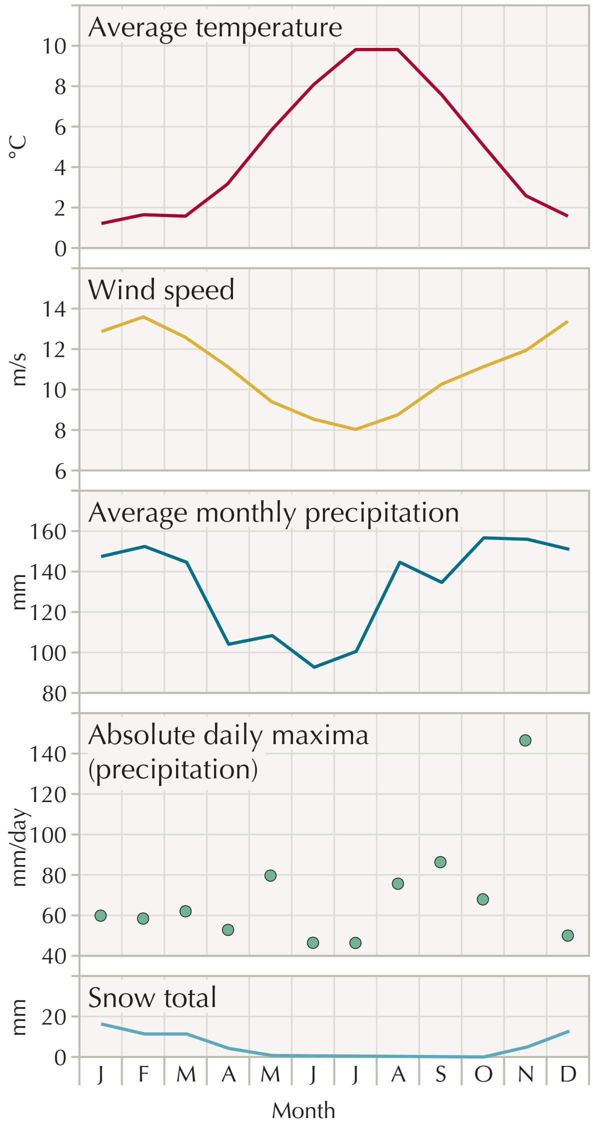


Fig. 2.8. Average temperature (red trace) and wind speed (yellow trace) at Stórhöfði, 1971–2000; average monthly precipitation (blue trace); snow totals (light blue trace) and absolute daily maxima (shown by green dots, in mm per day. (Modified from the Icelandic Meteorological Office.)

Offshore waves

Iceland's wave climate is severe, including measured offshore significant wave heights (the average height of one-third of the waves observed during a given period of time) of over 16 m and wave peak periods of up to 20 seconds. Cyclones from North America pass over Iceland from the southwest, generating high waves upon reaching Southwest Iceland. Deep cyclones sometimes stagnate east or north of the country for several days and also generate high waves.

In January 1990, for example, an extreme storm hit the south coast of Iceland. At its peak intensity, the atmospheric pressure plunged to

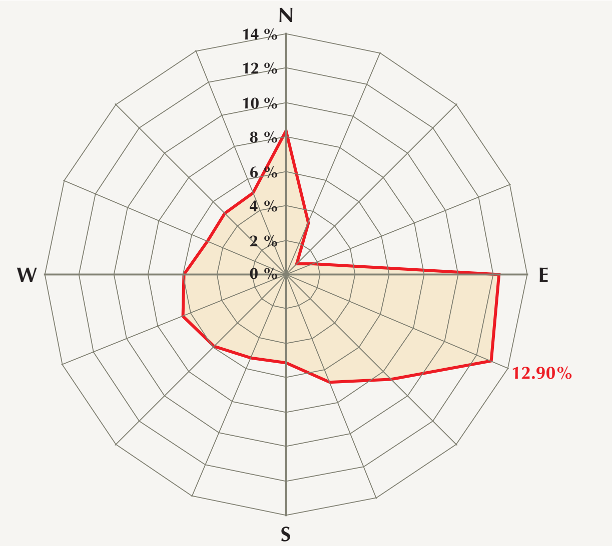


Fig. 2.9. Wind direction frequency (%) at Stórhöfði, 1971–2000. Easterly winds prevail, with the low frequency of northeasterly winds being owed to the sheltering effect of the Eyjafjallajökull glacier and mountain mass on the mainland. (Modified from the Icelandic Meteorological Office.)

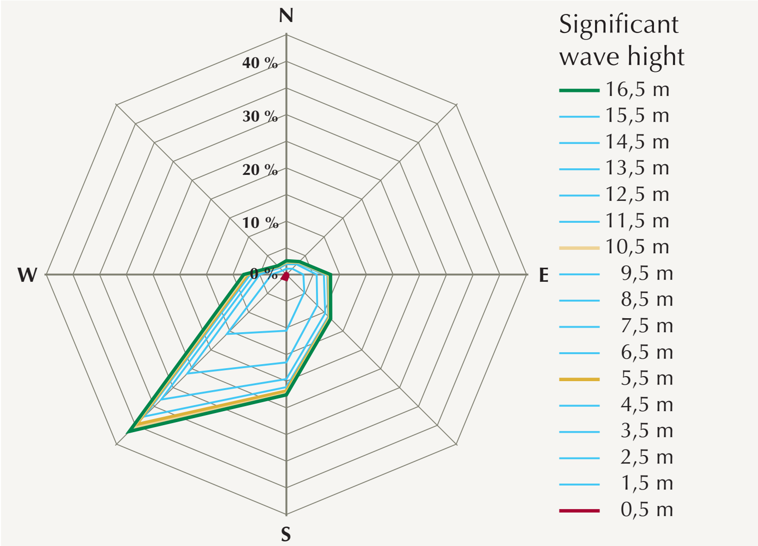


Fig. 2.10. Offshore wave statistics based on significant wave heights off Surtsey at location 63°N,21,0°W for the ECMWF hindcasted data for the period 1979 to 2004. (Model: Icelandic Maritime Administration). The offshore wave statistics explain why the marine abrasion is greatest at the southwest and south coast, cf. Fig 2.24.

928 millibars at a location 200 km southwest of the country. The offshore wave buoy at Surtsey recorded significant wave height of 16.68 m, with peak period of 19.4 seconds.

Offshore wave data is available since 1988, measured off Surtsey (63°17,14 N, 20°20,70 W) at a depth of 130 m and off Garðskagi (64°03,27 N, 22°56,57 W a depth of 80 m (Fig. 2.10). Wave hindcast data are available from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Terrestrial life

Flora

Plant colonisation has been closely studied on Surtsey ever since the island was formed. Microbial moulds, bacteria and fungi were quick to establish themselves in the fresh volcanic substrate (Schwabe 1970a, Smith 1970). The first vascular plant to be noted growing there was found in 1965 (Sturla Friðriksson 1966a; Eyþór Einarsson 1968), mosses became visible in 1968 (Bergþór Jóhannsson 1968) and lichens were discovered on the lava in 1970 (Hörður Kristinsson 1972). Vascular plants have proved of far greater significance in vegetation development than mosses and lichens. Consequently, this element of the flora has been studied most intensely. The island has been visited every summer by a team of botanists and a record kept of colonising species and their fate.

Vascular plants

The biological expedition to Surtsey in 2005 recorded 51 vascular species. On the other hand, an overall total of 60 species has been recorded since 1965. In other words, there have been nine unsuccessful colonisation attempts. About 30 species have managed to establish viable populations and spread on the island, and most of these are now found in some of the 23 permanently established study plots. While forb and grass species are most prominent (32 and 14 respectively) in the flora, other prominent taxonomic groups include sedges and rushes (5 species), shrubs (4 species) and ferns (2 species) (Table 2.2, Appendix 2). The most widespread plant species on Surtsey are sea sandwort *Honckenya peploides*, procumbent pearlwort *Sagina procumbens*, common mouse-ear *Cerastium alpinum*, annual meadow-grass *Poa annua* and lyme grass *Leymus arenarius* (Table 2.3).

	Species	Species status in 2005		
	1965–2005	Existing	Viable populations	Within permanent plots
Pterydophytes	3	3	1	
Monocots				
Grasses	14	12	7	7
sedges and rushes	6	5	1	2
Orchids	1			
Dicots				
forbs	32	27	19	15
dwarf shrubs	4	4	2	1
	60	51	30	25

Table 2.2. Overview by taxonomic group of vascular species recorded on Surtsey, showing their success of establishment.

Species		Number of plots
Sea sandwort	*Honckenya peploides*	18
Procumbent pearlwort	*Sagina procumbens*	12
Common mouse-ear	*Cerastium fontanum*	10
Annual meadow-grass	*Poa annua*	9
Lyme-grass	*Leymus arenarius*	8
Smooth meadow-grass	*Poa pratensis*	8
Common chickweed	*Stellaria media*	8
Common scurvygrass	*Cochlearia officinalis*	7
Arctic fescue	*Festuca rubra*	7
Oysterplant	*Mertensia maritima*	7
Sea mayweed	*Tripleurospermum maritimum*	6
Reflexed saltmarsh-grass	*Puccinellia coarctata*	6

Table 2.3. The most common vascular plants on Surtsey and the number of permanent plots where each species was observed in a 2004 survey. The species shown on the list occurred in more than a quarter of the 23 permanent study plots.

Most of the vascular plant species on Surtsey are common elsewhere in the Vestmannaeyjar archipelago, which is probably the main source of species colonising Surtsey. As for the Icelandic mainland, it has every plant species that has been noted on Surtsey. Although Surtsey is the southernmost island of Iceland, there has been no indication of species colonising the island from distant sources (Borgþór Magnússon et al. 1996).

The wild flora of Heimaey contains some 150 species of vascular plants. Other islands in the Vestmannaeyjar archipelago harbour only 2–30 species, corresponding to their aerial size, which ranges from 0.01 to 0.46 km² (Sturla Friðriksson and Björn Johnsen 1967). Thus the number of species growing on Surtsey has actually surpassed that of the smaller islands in the archipelago. This may be explained by Surtsey's considerably larger

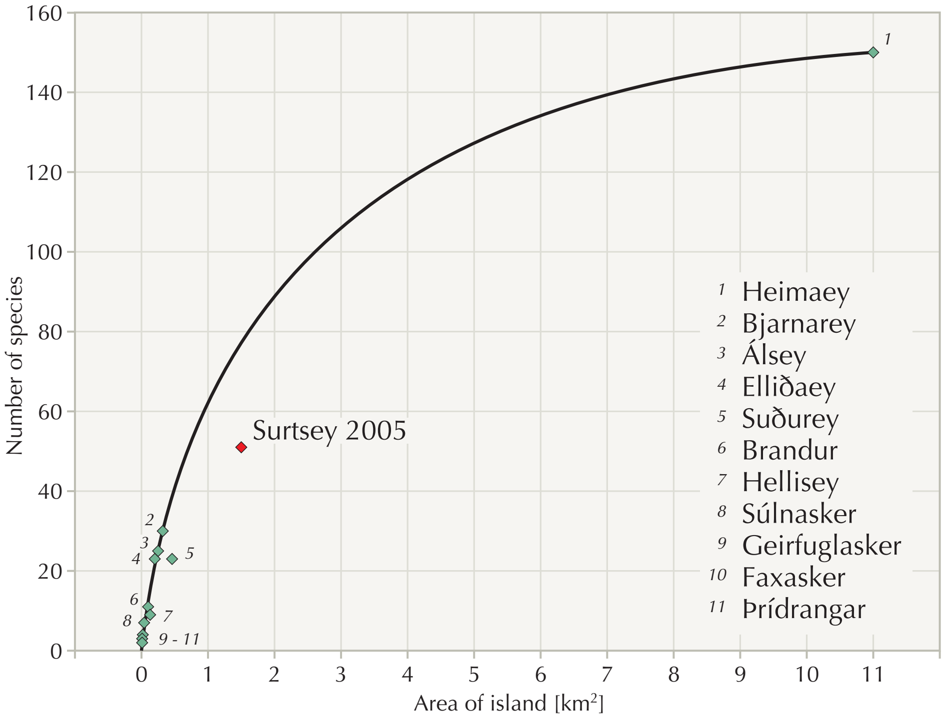


Fig. 2.11. Number of vascular plant species found on individual islands in the Vestmannaeyjar archipelago in relation to their areal size (Sturla Friðriksson and Björn Johnsen 1967). A curve was drawn to indicate the relationship and show the current (2005) position of Surtsey.

Sea sandwort and lyme grass on the sand-filled lava on eastern Surtsey. The species are widely dispersed on the island. As other plant species they have colonised Surtsey from the neighbouring islands and the mainland seen in the background (Photo: Borgþór Magnússon 2005).

size and its greater diversity of habitats compared to the other volcanic islands, which are much older and more eroded. It is likely that species richness will continue to increase on Surtsey during the next few decades and peak at about 70–90 species, after which it is expected to decline with the continual erosion and shrinking of the island (Fig. 2.11).

Bryophytes

Bryophyte colonisation was carefully documented during the first decade after the eruption ended. In 1967 the first two moss species, *Funaria hygrometrica* and *Bryum argenteum*, were found growing close to steam holes (Bergþór Jóhannsson 1968). Already in 1973, 69 species of bryophytes had been recorded (Skúli Magnússon and Sturla Friðriksson 1974). The most recent survey of bryophytes, carried out within permanent vegetation plots in 2003, also added a few new species to former finds. Altogether, 75 species of bryophytes have been recorded on Surtsey, sixteen of which were found within the permanent study plots during the 2003 survey (Appendix 3). The most common and widely dispersed bryophytes on the island in 2003 were the mosses *Schistidium maritimum*, *Bryum dichotomum*, *B. argenteum*, *Ceratodon purpureus* and *Racomitrium eriocides* (Table 2.4). Another moss, *Racomitrium lanuginosum*, is abundant in the large, sheltered western crater, Surtungur, where it has formed a moss carpet that somewhat resembles the extensive *Racomitrium* carpets covering recent lava flows in areas of high precipitation on the Icelandic mainland.

The bryophytes colonizing the lava of Surtsey are similar to the flora found in young lava flows and volcanic areas of southern Iceland. However, maritime species are more prominent in the Surtseyan flora. All bryophytes discovered on Surtsey so far have been found elsewhere in Iceland.

Lava blocks overgrown by the moss *Racometrium lanuginosum*. (Photo: Hervé Jezequel 2005).

Species	Number of plots
Schistidium maritimum	12
Bryum dichotomum	10
Bryum argenteum	8
Ceratodon purpureus	6
Racomitrium ericoides	6

Table 2.4. The most common bryophyte species on Surtsey and the number of permanent plots where each particular species was found in a 2003 survey. The species shown on the list occurred in more than a quarter of the 23 permanent plots.

Lichens

Altogether 71 species of lichens have been recorded on Surtsey (Appendix 4). The first lichen to be found there was *Trapelia coarctata*, in July 1970 (Hörður Kristinsson 1972). It was growing around steam holes on the outside wall of the crater Surtungur and had numerous mature ascocarps, which strongly indicates that it had been there since at least the year before. Also in 1970, a further two species of lichens, *Stereocaulon vesuvianum* and *Placopsis gelida*, were found in the lava fields around the crater. Although these specimens were barely visible at the time, they developed quickly over the next few years. By 1973, 12 species of lichens had been recorded from Surtsey, including *Stereocaulon capitellatum*, which together with the above-mentioned species became one of the foremost colonisers of the lava fields; *Acarospora smaragdula*, which colonised all the lava peaks; and *Psilolechia leprosa*, which became the main coloniser of rifts and caves in the lava field.

The next decades saw the addition of only a few more species, until a rapid increase in the number of lichen species following gull colonistation in the mid-1990s. Thus only some 32 species of lichens had been recorded by 1990, but by 1998 species numbers jumped to 58. The reasons for the rapid increase in lichen species included favourable conditions within the relatively sheltered crater of Surtungur as well as

The lichen *Xanthoria parietina* and the moss *Ulota phyllantha* growing on a lava surface. (Photo: Erling Ólafsson 2005).

While the fungus *Entoloma sericeum* is a common grassland species in Iceland, it was not until 2005 that a specimen was first found on Surtsey (Photo: Sigurður H. Magnússon 2005).

soil formation around the seagull colony, which provided conditions for various kinds of soil-inhabiting lichens such as *Cladonia* spp., *Leptogium lichenoides* and *Peltigera canina*. Several rock-inhabiting species were also brought in directly by the birds, e.g. *Caloplaca verruculifera* and *Xanthoria parietina*.

All lichens recorded in Surtsey, with the exception of one or two inconspicuous species, have been found elsewhere in Iceland. Colonisation of the new lava fields is also characterized by the same pioneer species as in other lava fields on the southern coast of Iceland. It is however remarkable that some of the most common basaltic lichens in Iceland, including *Rhizocarpon geographicum* and *Tremolecia atrata*, have not yet been found on Surtsey.

Fungi

So far, 24 species of fungi have been identified from Surtsey (Appendix 5), although the island's specific mycota has yet to be studied in detail.

By April 1965, five species of marine fungi were identified on bits of driftwood and dead algae, primarily *Ascophyllum*, together with at least three unidentified species of *Pythium* and *Phoma* (Johnson 1966; Johnson and Cavaliere 1968). In 1968 three species of anamorphic fungi (moulds) grew in raw cultures of algae from substrates of moist tephra and lava taken near fumaroles near the two craters (Schwabe 1970a). Henriksson and Henriksson (1974) isolated and

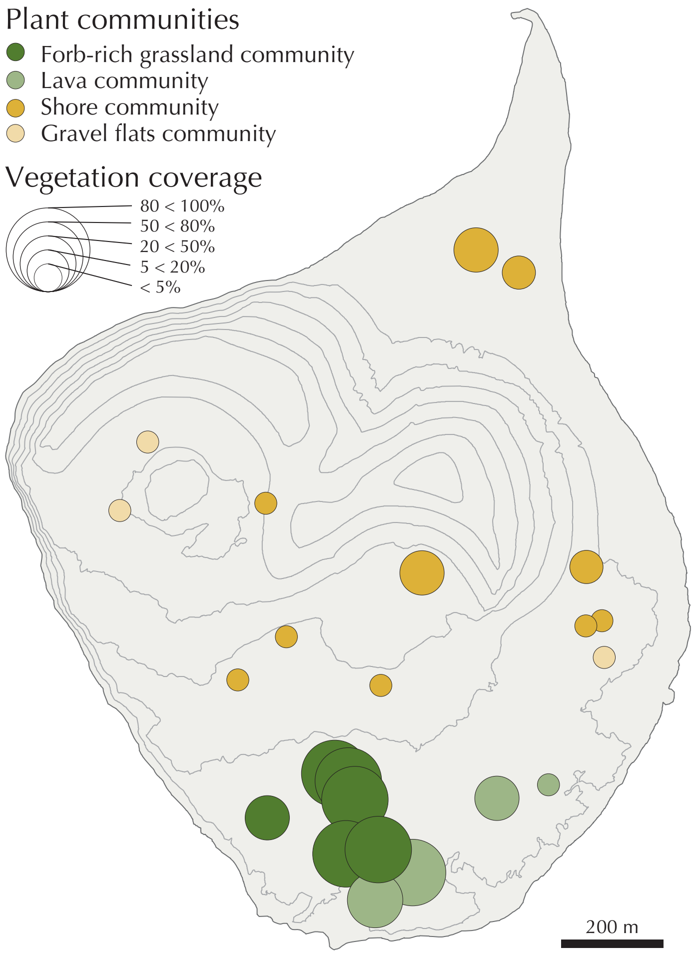


Fig. 2.12. Permanent study plots on Surtsey and community classification of the vegetation found within them in 2004. Total vegetation cover is also shown.

Shore community on the northern coast of Surtsey, composed of sea sandwort, lyme grass, oyster plant and sea rocket (Photo: Borgþór Magnússon 2005).

Thrift, a species of the gravel flat community, recently established on Surtsey. (Photo: Árni Bragason 2004).

identified 10 species of fungi from soil samples of the surface layer (0–20 mm) that were collected at 21 localities in July 1972. No soil- or freshwater-inhabiting aquatic fungi were found on Surtsey between 1964 and 1972, when their possible presence was being monitored by T. W. Johnson together with his students and co-workers.

Studies in 1996 on the microbial activity in three different soils (Frederiksen et al. 2000) showed that there were few fungal hyphae in bare soil, a medium number in areas with shore community, while by far the most hyphae were measured in the soils of the gull colony.

Vegetation

Plants have dispersed and become established in all parts of Surtsey. The only sections of the island which remain mostly devoid of plant life are the steep palagonite hills in the middle of the island. However, the plant cover is still relatively thin, except at the gull colony on the southern lava plain (Fig. 2.12), where dense and rather diverse vegetation has developed over the last 20 years.

In 2004, vegetation analyses of the permanent study plots revealed four main vegetation types or communities on the island, as discussed below.

The most widespread vegetation community

Lava community on southern Surtsey. Procumbent pearlwort, reflexed saltmarsh-grass and scurvygrass are the most prominent species in this community. (Photo: Borgþór Magnússon 2004).

on Surtsey is the **shore community**, which is found on sand substrates on the island. The main species are sea sandwort, lyme grass and oyster plant *Mertensia maritima*. On the low-lying point at the north end of the island, occasional sea rocket plants *Cakile arctica* are also found within this community. The plant cover ranges from 1–25%, and the species richness of vascular plants is only 1–4 per 100 m^2 plot. Due to the loose substrate, hardly any bryophytes are recorded. This community is common on the sandy shores of southern Iceland.

The first stages of a **gravel flat community** have started to develop on the upper part of the island. Growing on fine-textured lava and tephra substrate, the gravel flat community is most common on the lava flats around the large western crater of Surtungur. The characteristic species are northern rock-cress *Arabidopsis petraea*, sea campion *Silene uniflora* and thrift *Armeria maritima*, but sea sandwort also occurs. Plant cover ranges from 1–5%, and the species richness is 3–7 species per plot, slightly exceeding that of the shore community. Scattered bryophyte growth occurs, with the main two species being *Racomitrium ericoides* and *Schistidium flexipile*.

The lava community, thriving on the fringes of the gull colony, may be seen as the first stage in vegetation succession driven by nutrient enrichment from the birds. The main species of this community are the procumbent pearlwort, reflexed saltmarsh-grass *Puccinellia coarctata*, and common scurvygrass *Cochlearia officinalis*. The procumbent pearlwort is usually the first of these species to colonise any area of new lava that is being affected by expansion of the gull colony. In this community the plant cover varies tremendously, or from 1–95%, depending on how long the site has been affected by the gulls. Species richness is relatively high for Surtsey, or 4–9 vascular species per plot. This community includes several bryophyte species, whose total cover reaches up to 10% and whose most common species are *Bryum dichotomum*, *Ceratodon purpureus* and *Schistidium maritimum*.

In the central and oldest part of the gull colony, a **forb-rich grassland community** has developed. This community type is found both on exposed lava and on lava stretches filled over with sand, with the species composition varying

Forb-rich grassland in the middle of the seagull colony on southern Surtsey. Sea mayweed in the foreground. (Photo: Borgþór Magnússon 2005).

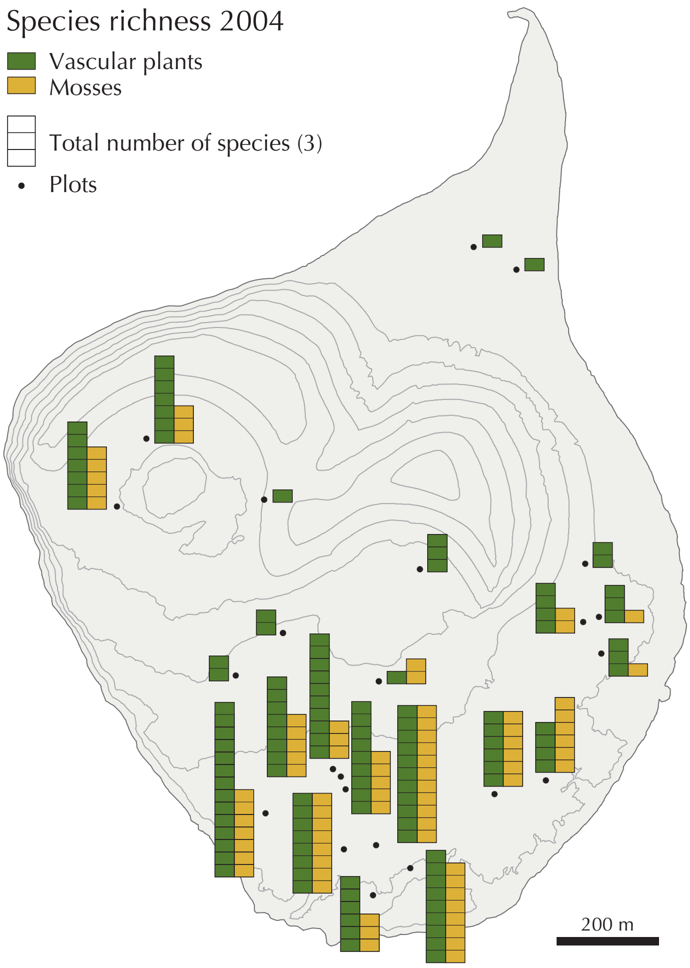


Fig. 2.13. Diversity of moss and vascular plant species in permanent study plots on Surtsey in 2004. Plots within the gull colony in the southern part of the island show the highest species diversity.

Northern fulmar was the first bird confirmed breeding on Surtsey in 1970 and is now the most common breeding bird on the island. (Photo: Torgny Nordin 2003).

slightly according to the substrate. The forb-rich grassland is strongly affected by the breeding gulls through their provision of rich nutrients, introduction of new plant species and nest-building activities. Having the densest and most diverse vegetation on Surtsey, this community demonstrates plant cover ranging from 40–100% and a species richness for vascular plants varying from 6 to 14 per plot (Fig. 2.12; 2.13). Considering grasses, the dominant and characteristic plants of this community are smooth meadow-grass, annual meadow-grass *Poa annua*, arctic fescue *Festuca rubra* and lyme grass. Common forbs include the common mouse-ear, sea mayweed *Tripleurospermum maritimum*, common chickweed *Stellaria media*, scurvygrass and sea sandwort. Bryophyte diversity is relatively high, with permanent plots yielding 3–9 species, of which *Bryum dichotomum*, *Bryum argenteum* and *Schistidium maritimum* are most common. Surtsey's forb-rich grassland is beginning to resemble older eutrophic grasslands found in bird colonies elsewhere in the Vestmannaeyjar archipelago.

Birds

Surtsey had just risen above the ocean surface when the first birds made their landfall. Gulls were seen touching down on the island between eruption bursts on 1 December 1963, only two weeks after the eruption started (Sturla Friðriksson 1964; Finnur Guðmundsson 1966). Since then, a number of bird species have been recorded on or near the island. Some of them are on feeding trips from their breeding colonies at neighbouring islands in the Vestmannaeyjar archipelago. Others are transient migrants, en route between breeding areas elsewhere in Iceland or the Arctic and their wintering grounds in Europe or Africa. Some are straggling immature birds or non-breeders from other parts of Iceland. Still others are incidental vagrants from either side of the North Atlantic (Ævar Petersen 1993).

Birds on Surtsey were observed regularly from 1966 to 1980, primarily to record migrants staging there in spring and autumn but also to monitor vagrant species and indications of breeding. Museum specimens were collected during these visits. During these early years, the entire island was monitored at intervals, carefully recording any observations of birds on land. After the first confirmed breeding on the island in 1970, nests were mapped and birds counted in conjunction with other biological surveys. Thus the main aspects of avian history on Surtsey are fairly well known (Borgþór Magnússon and Erling Ólafsson 2003). In 1990 and 2003, a breeding bird census was conducted on the island, and bird distribution maps were compiled.

General composition of the bird fauna

Altogether, 89 bird species have been found on Surtsey (Appendix 6); half (45) of them are water birds, while the other half (44) are terrestrial (here including freshwater) birds. Fifty-seven (57) species breed elsewhere in Iceland. The remaining species (32) are: vagrants in regard to Iceland (12), birds which are primarily vagrants but also rare or incidental breeders (9), regular transient migrants that breed in Greenland or Canada (5), and winter visitors (6). Of the vagrant species, the majority are European in origin, one is Holarctic and still another is North-American in origin.

The breeding species

By 2005, thirteen species of birds had been found nesting on the island of which twelve appear to breed annually (Table 2.5). In addition, a few pairs of arctic terns *Sterna paradisaea* nested (unsuccessfully) in 1975–1978 and the raven *Corvus corax* has built nests in the walls of the large lava crater, without ever laying eggs.

The black guillemot *Cepphus grylle* and northern fulmar *Fulmarus glacialis* were the first bird species found breeding on Surtsey; this was in 1970, three years after the cessation of volcanic activity (Erling Ólafsson 1971; Finnur Guðmundsson 1972). As early as 1966, however, the kittiwake *Rissa tridactyla* and black guillemot had begun prospecting for nest sites, but were probably prevented from actual nesting by the volcanic activity at the nearby crater islands, Syrtlingur and Jólnir (Finnur Guðmundsson 1967). By 1968, the northern fulmar had also been sighted as starting to occupy ledges (Finnur Guðmundsson 1970).

In 1990 a census was organised of the numbers and distribution of breeding birds; six breeding species were recorded, with the fulmar ranking as the most common breeder (120 pairs), followed closely by the lesser black-backed gull. Similar census in 2003 revealed eleven breeding species. Northern fulmar was still the most common species (350–400 pairs), followed by the lesser black-backed gull (150–200 pairs), kittiwake (130 pairs) and then the great black-backed gull, black guillemot and herring gull (each with 35–40 pairs). With only a single pair, the white wagtail *Motacilla alba* was the rarest of the Surtsey breeding birds in 2003 (Table 2.5). In 2004 food was seen delivered to at least two Puffin nests, the first evidence of breeding, and in 2005 birds attended two likely nest sites.

Species breeding		Year first confirmed	No of breeding pairs in 1990	No of breeding pairs in 2003
Black guillemot	*Cepphus grylle*	1970	15	35–40
Northern fulmar	*Fulmarus glacialis*	1970	120	350–400
Great black-backed gull	*Larus marinus*	1974	35	35
Kittiwake	*Rissa tridactyla*	1975	4	130
Arctic tern	*Sterna paradisaea*	1975	0	0
Herring gull	*L. argentatus*	1981	25	35–40
Lesser black-backed gull	*L. fuscus*	1985	120	150–200
Glaucous gull	*L. hyperboreus*	1993		4–5
Snow bunting	*Plectrophenax nivalis*	1996		11
White wagtail	*Motacilla alba*	2002		1
Greylag goose	*Anser anser*	2002		2
Meadow pipit	*Anthus pratensis*	2002		2
Puffin	*Fratercula arctica*	2004		0

Table 2.5. Breeding birds on Surtsey.

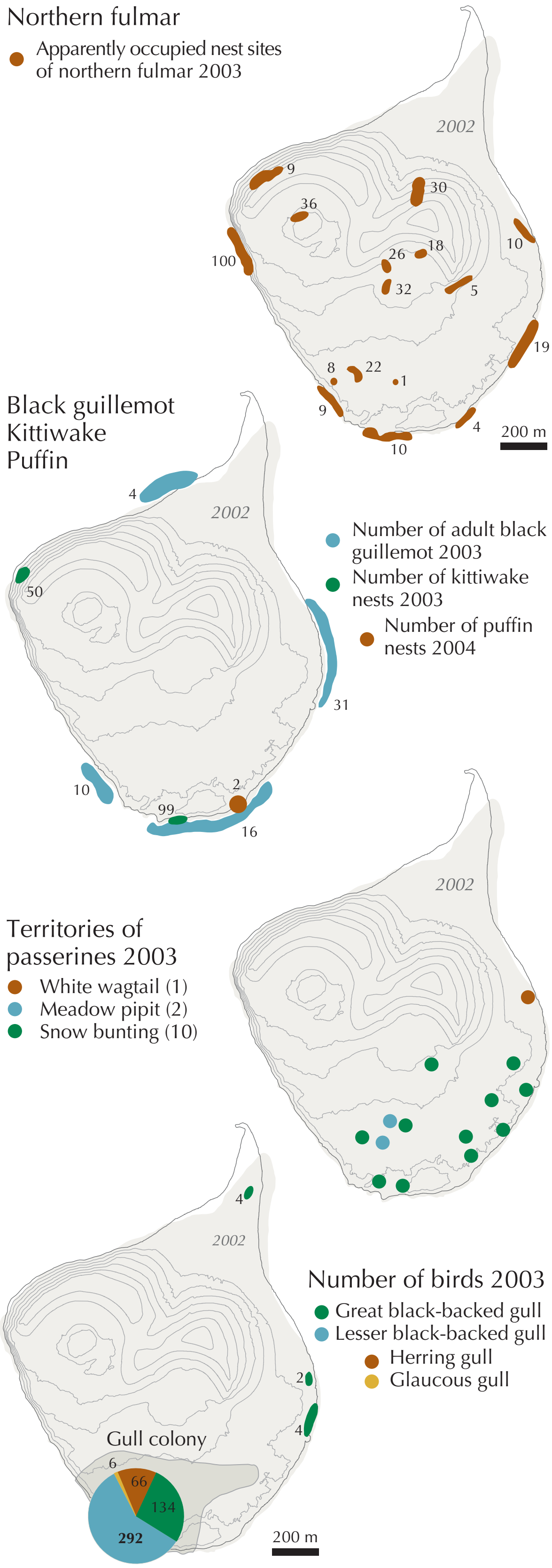


Fig. 2.14. Distribution maps for breeding birds on Surtsey.

On the whole, Surtsey bird populations have stayed more or less stable or have increased over time, with the exception of the arctic tern, which only bred there between 1975 and 1978. The fulmar and lesser black-backed gull have greatly increased in numbers, which is in line with their general population trends elsewhere in Iceland (Ævar Petersen 1998). The 2003 distribution of breeding species is shown on Fig. 2.14.

The four species of breeding gulls form a common breeding colony on the lava fields in the southern part of the island. This sort of community nesting involving four gull species is unique in Iceland. As a result of increasing population, the colony area has expanded in every direction except to the north, where blowing sand is perhaps the limiting factor. Great black-backed gulls nest primarily in the epicentre of the gull colony; lesser black-backed gulls and herring gulls flank them towards the southwest, south and east; and glaucous gulls choose their sites primarily east of the epicentre. In addition, five great black-backed gull pairs nested solitarily outside the main colony in 2003.

Migratory birds and vagrants

Bird migration was monitored by observers stationed on the island from 1966 to 1971, mainly during spring but also in autumn (Finnur Guðmundsson 1966, 1970, 1972) when the island was almost completely barren. Insect-feeding passerine species, such as the wheatear *Oenanthe oenanthe*, meadow pipit *Anthus pratensis* and white wagtail, have been among the most frequent migrants and are common breeders in Iceland. High-Arctic migrants have included the turnstone *Arenaria interpres* (a wader) and snow bunting *Plectrophenax nivalis* (a passerine). The latter were found to have grit (mineral stones) in the stomachs, originating from the British Isles (Sturla Friðriksson and Haraldur Sigurðsson 1969). Despite being relatively inconspicuous in the Icelandic bird fauna, passerines have featured highly among terrestrial migrants visiting Surtsey. The wader staging there most frequently is the oystercatcher.

The numbers of straggling species (vagrants) recorded depends principally on the length of

A newly fledged snowbunting in Surtsey. Snowbunting was the first landbird to breed on Surtsey beginning in 1996. (Photo: Daníel Bergmann 2003).

period and time of year when observations are carried out. In the early years of the island's formation, regular observations occurred during the migration periods of spring and autumn. Two very rare vagrant species have been sighted on Surtsey: the European squacco heron *Ardeola ralloides* and the North American northern oriole *Icterus galbula*. The former instance is the only one recorded for Iceland, while the latter was the third. Other vagrant species sighted on Surtsey generally include annual vagrants common to Iceland.

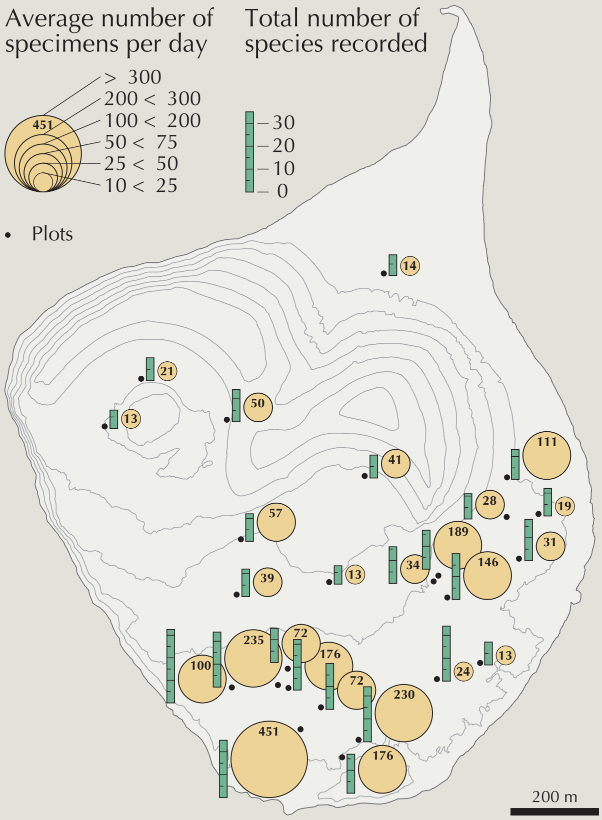
In terms of migratory birds, Surtsey should be considered from an international perspective. Migratory birds link this location to other corners of the world, whether to the south (where the birds over-winter) or north (where they seek their breeding grounds). Furthermore, birds bring with them and on them life forms such as seeds and insects; these play their own roles of whatever significance to the developing island ecosystem (Sturla Friðriksson 1968, 1970b; Sturla Friðriksson and Haraldur Sigurðsson 1969).

Invertebrates

Phylum/Order	English name	Number of identified species
ARTHROPODA	Joint-legged animals	
Collembola	Springtails	24
Protura	Proturans	1
Hemiptera	True bugs	7
Thysanoptera	Thrips	3
Mallophaga	Lice	1
Neuroptera	Lacewings	1
Trichoptera	Caddis flies	4
Lepidoptera	Butterflies	21
Coleoptera	Beetles	22
Hymenoptera	Hymenopterans	28
Diptera	True flies	136
Siphonaptera	Fleas	1
Araneae	Spiders	13
Acari	Mites and ticks	62
ANNELIDA	Segmented worms	
Oligochaeta	Earthworms	2
MOLLUSCA	Molluscs	
Gastropoda	Snails and slugs	2
NEMATODA	Roundworms	2
ROTIFERA	Rotifers	6
Total		336

Table 2.6. Terrestrial invertebrates on Surtsey. Number of species found until 2004.

Invertebrate diversity on Surtsey island



The tiny weevil *Ceutorhynchus insularis*, which is abundant on scurvygrass on Surtsey, was first discovered in 1968 on one of the Vestmannaeyjar islands. It was originally believed to be a new species to science and was described as such in 1971. Later on, similar specimens were discovered in samples from the Hebrides Islands off Scotland.

The forb-rich grassland vegetation of the gull colony supports higher diversity and abundance of invertebrates than do other parts of the island.

The results of pitfall trapping within permanent plots show that the diversity of Surtseyan invertebrates is considerably greater within the gull colony than in other parts of the island. Furthermore, the abundance, or number of individuals, is also shown to be greater (Fig 2.15).

However, a few permanent plots, located in a shore community on the eastern part of the island where sea sandwort is the dominant species, also appear to be relatively rich in invertebrates. One of these plots is located at the helicopter platform, where gulls tend to rest and enrich the soil with nutrients. As a result, the vegetation there is similar to that at the gull colony. The high abundance recorded at two other sites is caused by numerous individuals of a single species, the thrip *Taeniothrips atratus*, which has sea sandwort as its host plant.

A total of 335 invertebrate species has been found on Surtsey (Appendix 7; Table 2.6). These include arthropods, molluscs, annelids, nematodes and rotatorians, approximately half of which have become permanently established. Although flying insects are most conspicuous, soil animals are most numerous. There are as of yet no endemic invertebrates on Surtsey. One species of special interest is *Ceutorrhyncus insularis*, a very small snout beetle that feeds on scurvy grass and is extremely rare on a global scale.

The establishment of a gull colony clearly boosted the insect fauna on Surtsey (Fig. 2.15). A few species such as *Atheta graminicola* are completely dependent on the gull colony, even though others such as *Amara quenseli* prefer the harsh tephra ground elsewhere (see box on this page).

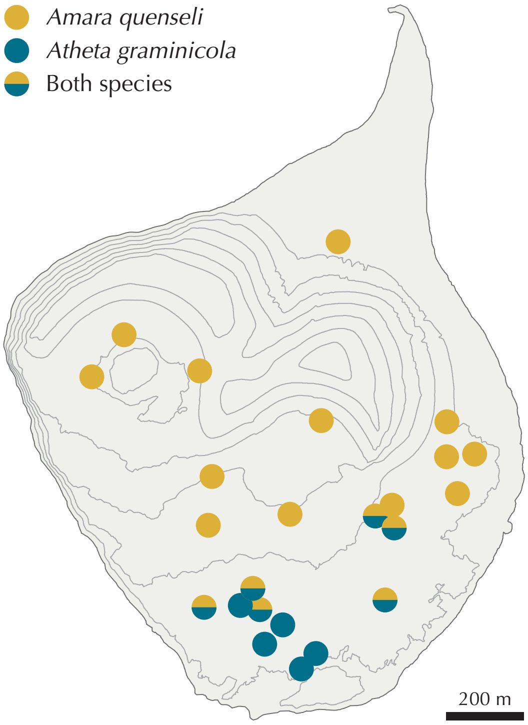


Fig. 2.15. The diverse, forb-rich grassland vegetation in the gull colony is favoured by some, but not all species of invertebrates. As an example of a species clearly favouring this type of vegetation, the staphilinid beetle *Atheta graminicola* is found only within the gull colony and by the helicopter platform, where similar vegetation occurs. The carabid beetle *Amara quenseli*, in sharp contrast, prefers a barren, sandy substrate, as occurs in the open gravel flat- and shore communities.

Marine life

Benthos

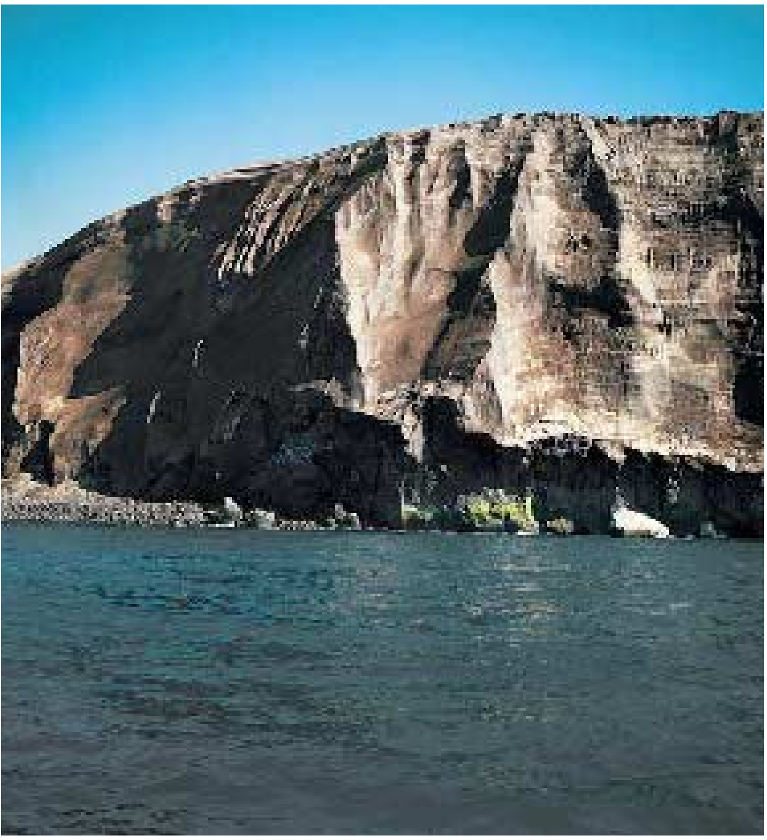
Monitoring of the marine benthos around Surtsey began in 1964. About 80 species of macroalgae and 180 benthic animal species have been identified in the rocky littoral and hard-bottom sublittoral zones around Surtsey (Appendices 8 and 9a and b). The number of benthic species found along the coast of neighbouring islands in the Vestmannaeyjar archipelago is considerably higher. With respect to marine vegetation, the most striking difference in Surtsey is its complete lack of the large fucoids which dominate littoral vegetation by the other islands. In Surtsey's sublittoral zone, there is also a lack of crustose red algae, whereas red crusts, especially crustose corallines, are prominent among vegetation along the coast of other Vestmannaeyjar islands. The instability of the Surtseyan substrate is probably what prevents perennial fucoids from establishing viable populations in Surtsey's littoral zone. Certainly there is no lack of propagules, because each year fertile fragments of fucoids are found as drift on Surtsey. For the sublittoral crustose species, erosion and sand scouring could pose potential problems; additionally, many of the crustose species have heavy spores that currents are unlikely to sweep far away. For comparison, it might be pointed out that crustose red algae are already well established on the lava formed in 1973 at Heimaey, 10 years after the Surtsey eruption. This lava is, however, adjacent to established macroalgal vegetation that was unaffected by the eruption (Karl Gunnarsson 2000).

Littoral zone

Along the west, south and east coast of Surtsey, the littoral zone substrate is composed of bedrock and large boulders. In the northern area, the substrate consists mostly of sand or boulders embedded in sand. The entire shoreline has been constantly eroded by heavy breakers, especially during severe southerly storms. A buoy monitoring waves just south of Surtsey has registered wave heights of some 16 m during winter storms (see above). The southwestern shore has been most intensely affected, in some years receding over 50 m. Although the most stable shore borders the eastern side of Surtsey, frequent scouring takes place even there, with waves and currents transporting sand northwards and depositing it on the northern spit.

Rocks all around Surtsey display algal growth. Even the boulders embedded in sand on the northern spit support fast-growing algae during calm summer periods, and various annual algae species have colonised littoral cliffs on the eastern, southern and western shores. In the beginning, there were very few species and cover was scanty, but in recent years a number of species are found in the littoral zone and have achieved a total cover of over 60%. The most common species are diatoms in mucilage tubes (*Schizonema* type) and the green filamentous algae *Ulothrix flacca*, which together comprise over 80% of vegetation cover in the littoral zone.

In the island's southern and western sections, erosion has formed steep cliffs, rendering the shore inaccessible. Since 1970, the only part of



The vegetation in the Surtsey littoral zone is characterised by two distinct algal communities (see Fig. 2.16). (Photo: Karl Gunnarsson 1991).

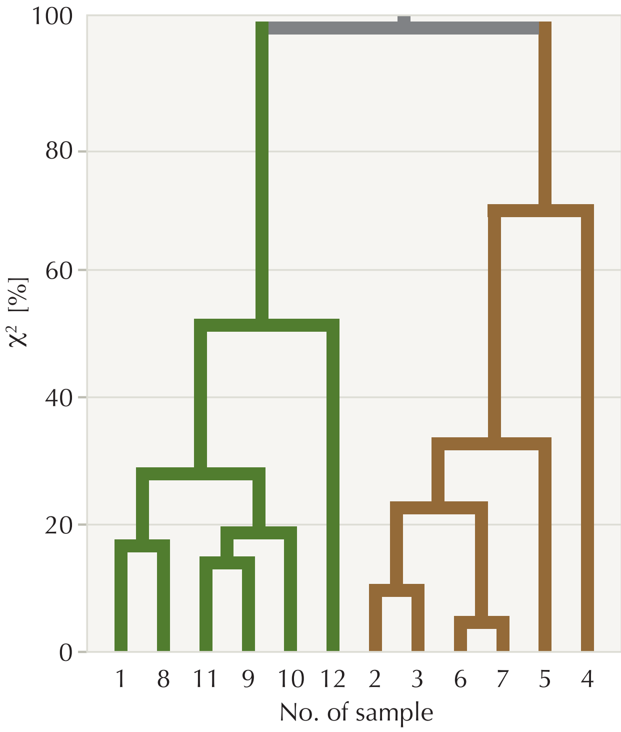


Fig. 2.16. Cluster analysis of samples from varying depths in the Surtsey littoral zone. Two communities can be distinguished: an upper one dominated by green algae and a lower one dominated by diatoms and brown algae. The numbers refer to sampling depths. Sample 1 is taken at low water mark at spring tide; sample 12 is taken at the highest water level.

the shoreline which has a hard substrate and has also been accessible and therefore possible to examine is the eastern shore.

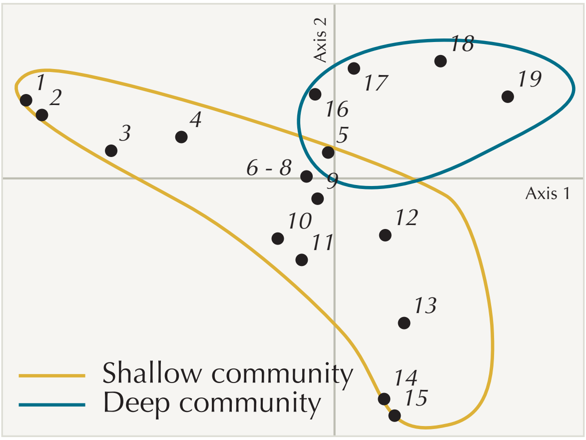
Two algal belts are distinguishable in the littoral zone (Fig. 2.16): an upper belt, green in colour and dominated by the green algae *Ulothrix flacca, Enteromorpha intestinalis* and *Urospora penicilliformis*; and a lower belt dominated by brown-coloured species, among which *Petalonia fascia, Petalonia zosterifolia, Scytosiphon lomentarius, Ectocarpus siliculosus* and *Porphyra umbilicalis* (a brown-coloured red algae) are most common. At the lowest extreme of the littoral zone, the brown kelp species *Alaria esculenta* encroaches from the sublittoral zone, covering most of the rocks (Sigurður Jónsson et al. 1987).

The littoral fauna is poor, although small crustaceans have been found amongst the filamentous algae, including the harpacticoid *Harpacticus arcticus*. The sessile animal most often observed in Surtsey's littoral zone is the acorn barnacle *Semibalanus balanoides*, which colonises the lower part of the littoral zone each spring, only to disappear the following winter. In summer tiny young mussels *Mytilus edulis* are also found in the littoral zone (Erlingur Hauksson 2000).

In general, most plant species that have been identified in the littoral zone are annual species. All of the perennial species found were still in their first year and without exception disappeared again before the following spring. None of the large perennial fucoids dominating the mainland coast and rocky shores elsewhere in the Vestmannaeyjar archipelago were found to be growing in Surtsey until 1997, when a small *Fucus spiralis* plant from earlier the same summer was noted. No fucoid plants could be found upon examining the same site a year later (Sigurður Jónsson and Karl Gunnarsson 2000).

Sublittoral zone

The substrate in the sublittoral zone west, south and east of the island is made up of bedrock and boulders, often with sand in-between. In the



1 *Halosiphon tomentosum*
2 *Desmarestia viridis*
3 *Monostroma grevillei*
4 *Polysiphonia stricta*
5 *Lomentaria orcadensis*
6 *Diatoma*
7 *Ectocarpus* sp.
8 *Haplospora* sp.
9 *Desmarestia ligulata*
10 *Alaria esculenta*
11 *Porphyra miniata*
12 *Laminaria hyperborea*
13 *Oscillatoria* sp.
14 *Chorda filum*
15 *Desmarestia aculeata*
16 *Delesseria sanguinea*
17 *Phycodrys rubens*
18 *Conchocelis rosea*
19 *Derbesia marina*

Fig. 2.17. Factorial correspondence analysis of principal algal species in the Surtsey sublittoral zone. Two communities can be distinguished: a shallow-water community dominated by fast-growing annual species, mostly brown algae (delineated by a yellow line) and a deeper-water community dominated by perennial red algae (bounded by the blue line).

northern sublittoral zone, the seabed is covered by sand. As vegetation is limited to hard substrate and little animal life occurs in the sand due to its constant motion, monitoring since 1969 has been confined to the hard substrate on the west, south and east coasts of Surtsey.

In recent years, two different communities have been noted on the sublittoral hard bottom (Fig. 2.17). Shallow water harbours a community of fast-growing opportunistic species like the brown algae *Alaria esculenta*, *Chorda filum* and *Desmarestia aculeata* and the red algal species *Porphyra miniata* and *Polysiphonia stricta*, with the dominant animal in this community being the mussel. In deeper waters from the 15-m level and farther down is a community of perennial vegetation including the large forest-forming kelp species *Laminaria hyperborea* and its undergrowth of red algal species such as *Delesseria sanguinea*, *Lomentaria orcadensis* and *Phycodrys rubens*. The sponge *Grantia compressa*, hydroids and bryozoans, the brittle star *Ophiopholis aculeata*, and various bivalves and gastropods are the most common invertebrate species in this community. The sea star *Asterias rubens* is frequently found devouring mussels and barnacles in both communities.

At depths of 25 to 30 m, hard substrate becomes scarcer, as sand covers most of the seabed. The hard-bottom community is dominated by sessile animals. Though the most conspicuous organism is the soft coral *Alcyonium digitatum*, which covers large areas of the hard substrate, hydroids also form extensive cover on the rocks at this depth range, especially the hydroid *Tubularia larynx*. Sea slugs are commonly found feeding on the hydroids.

Sand covers not only most of the bottom at the northern end of Surtsey but also predominates in the lower ranges of slopes all around the island. Its biota is not adequately studied. Early sampling of the sand and gravel substrate

Lemon sole, *Microstomus kitt*, lying on sand between rocks at a depth of 15 m in the sublittoral zone, Surtsey. (Photo: Karl Gunnarsson 1991).

Dense stands of the kelp species *Laminaria hyperborea* have developed on top of large boulders at depths of 10 to 20 m on the sublittoral slopes of Surtsey. This perennial plant is a structuring species in the sublittoral communities of nearby islands in the Vestmannaeyjar archipelago, forming a forest that serves as habitat for a number of epiphytic and turf-forming species of algae and animals. (Photo: Karl Gunnarsson 1997).

revealed that a number of species, mostly bristle worms and bivalves, had settled on the slopes. The majority of the animals were relatively small and sparsely distributed, the two most common species being *Pectinaria koreni* (bristle worm) and *Abra prismatica* (bivalve). Most of the species recorded were also common on the local areas of seabed that had escaped volcanic impact (Nicolaisen 1970).

At a depth of 5 to 10 m in the sublittoral zone at Surtsey, algal cover is at its maximum. The most common species are annuals such as the *Porphyra miniata*, *Chorda filum* and *Desmarestia viridis* pictured here. (Photo: Karl Gunnarsson 1997).

At 20- to 25-m depths, algae become rare and animals start to dominate Surtsey's hard bottom community. The orange-coloured soft coral *Alcyonium digitatum* is conspicuous in association with sponges and hydroids. (Photo: Karl Gunnarsson 1997).

Marine mammals

Marine mammals have been observed in the waters around Surtsey every year since the formation of the island (Table 2.7). Seals started basking on Surtsey shortly after the island's formation. Due to the constantly changing shoreline, however, they did not start breeding on the island until the 1980s, when erosion had begun to slow down.

There is no direct evidence of common seals *Phoca vitulina* breeding on Surtsey, but it seems likely, as pups have been seen at the shoreline in summer. Groups of common seals (0–20 adults and juveniles) are commonly seen at Surtsey during summer. Grey seals *Halichoerus grypus*, on the other hand, started pupping on the island as far back as 1983. In recent years, 30–50 newborn grey seal pups have been observed every autumn on the northern part of the island, lying on the sand as well as among the rocks. Their numbers peak in late September or October (Erlingur Hauksson 1992a).

Grey seals *Halichoerus grypus* breed on the northern spit of Surtsey, with pup birth usually peaking in October. This photo, showing two grey seal pups in Surtsey, was taken in October 1998. (Photo: Karl Gunnarsson).

Grey seal pups are born with the white natal hair cover which is shed 3 to 4 weeks after birth. During that period the pups stay on shore in their lairs and are fed by their mother a few times per day. (Photo: Karl Gunnarsson 2000).

Whales are frequently spotted just off the Surtsey coast. Three species have been positively identified: the killer whale *Orcinus orca*, minke whale *Balaenoptera acutorostrata* and harbour porpoise *Phocoena phocoena*. Dolphins *Lagenorhynchus* sp. have also been seen in pods close by the coast. The species most commonly noted during the summer is the killer whale, which has been seen in pods of three to seventy animals of different sizes, foraging near Surtsey.

Seals	
Grey seal	*Halichoerus grypus* (Fabricius, 1791)
Common seal	*Phoca vitulina* (Linnaeus, 1758)
Cataceans	
Minke whale	*Balaenoptera acutorostrata,* Lacepède, 1804
Killer whale	*Orcinus orca* (Linnaeus, 1758)
Harbour porpoise	*Phocoena phocoena* Linnaeus, 1758
Dolphins	*Lagenorhynchus* sp.

Table 2.7. Marine mammals observed on or in close proximity to Surtsey.

Lightning flashes in the eruption column during the submarine phase of the Surtsey eruption, December 1, 1963. (Photo: Sigurgeir Jónasson).

2.b History and development

Geological history

The Surtsey eruption

Eruption history

The eruption history of Surtsey island and its two short-lived neighbours is well known, mainly through the work of Sigurður Þórarinsson (1966, 1967; 1968) and Þorleifur Einarsson (1966). In addition, general outlines have been published (Sveinn P. Jakobsson and J. G. Moore 1982). Nevertheless, since the history of the eruption is of vital importance to understanding Surtseyan geology, the main events are listed below and are further summarised in Table 2.8.

The visible eruption started with hydromagmatic explosions along a 300 to 400 m long fissure trending 035°. This was on 14 November 1963, although the eruption had presumably broken through the sea floor a few days earlier without being noticed. The most recent pre-eruption sounding in the area had been taken in 1901 by the Royal Danish Hydrographic Office, showing a water depth of 128 m at the point recorded closest to the eruption site. Based on the general bathymetric configuration, the

Year	Month	Day(s)	
1963	Nov.	10?	Approximate beginning of eruption on the sea floor
	Nov.	14	First visible explosive activity at water surface, near the eastern vent
	Nov.	15	Emergence of the island of Surtsey
	Dec.	28	Submarine activity (Surtla) first visible 2.5 km ENE of Surtsey
1964	Jan.	6	Surtla activity over, after building a 100-m-high submarine ridge
	Jan.	31	Activity over at eastern Surtsey vent
	Feb.	1	Beginning of explosive activity at western Surtsey vent
	Apr.	4	Explosive activity over at western Surtsey vent; beginning of effusive phase
	Apr.	29	Completion of lava effusion from western Surtsey vent
	July	9	Resumption of lava effusion from western Surtsey vent
1965	May	11?	Possible beginning of submarine activity at Syrtlingur site
	May	17	Effusion of lava ceased at western Surtsey vent
	May	22	Beginning of visible explosive activity at Syrtlingur, 0.6 km ENE of Surtsey
	Oct.	17	Cessation of explosive activity at Syrtlingur
	Oct.	24	Syrtlingur completely washed away
	Oct.	end?	Probable beginning of eruptive activity, 1 km SW of Surtsey
	Dec.	26	Visible explosive activity SW of Surtsey
	Dec.	28	Emergence of the island of Jólnir
1966	May	late	Fault-bounded lagoon develops in northern part of Jólnir
	Aug.	10	Cessation of explosive activity in Jólnir
	Aug.	19	Beginning of effusive activity at eastern Surtsey vent
	Oct.	31	Jólnir completely washed away
	Dec.	12–17	Minor lava flow from vent on inner northwest wall of eastern tephra cone
1967	Jan.	1–4	Lava flows into north lagoon from vent on outer north slope of eastern tephra cone
	Jan.	1–8	Lava eruption from vent on inner north wall on eastern tephra cone
	Jan.	2	Tiny lava flow from vent on outer northeast slope of eastern tephra cone
	Jan.	2–7	Faults form on inner wall of eastern tephra cone; minor lava flow from lower fault
	June	5	Cessation of effusive activity at eastern Surtsey vent

Table 2.8. History of the Surtsey eruption, based on Sigurður Þórarinsson (1966, 1968).

The Surtsey eruption column on November 16, 1963. (Photo: Sigurður Þórarinsson).

pre-eruption water depth at the eruption site is estimated to have been 130 ± 5 m.

Emerging on 15 November 1963, the island grew rapidly in size. Two types of submarine, hydromagmatic explosions were most common: intermittent "cock's-tail" jets and a continuous uprush of tephra. All of these explosions were caused by hot magma being quenched in cold sea-water. Calculations and measurements on site indicate that the temperature of the magma was 1155°–1180° C, whereas the sea temperature in this area is around 10° C.

A crescent-shaped crater of finely-bedded tephra layers was built up between November 1963 and January 1964 (Fig. 2.18). On 31 January 1964, eruptions ceased in the eastern vent (Surtur), which until then had been the sole source of activity. On the following day, however, eruptions broke out once more in a northeast-trending fissure at the northwest side of that crater, where another crescent-shaped tephra crater soon formed (Surtungur), merged with the eastern tephra crater, and finally achieved a maximum height of 173 m above sea level. During the winter of 1963–1964, storm waves were severely destructive, carving broad abrasional platforms into the loose tephra of these two cones. On 4 April 1964, the eruption in Surtungur switched to an effusive Hawaiian-type lava phase. Clearly the island had at this point grown large enough to isolate the vent from inflowing seawater and thus protect the hot magma from being quenched.

Between 28 December 1963 and 6 January 1964, explosive submarine activity was visible about 2.0 km east-northeast of Surtsey. The eruption fissure there, estimated as 250 m long, created a submarine ridge called Surtla to over 100 m above the sea floor, but never raised it above the water surface. Apparently nothing but tephra was produced at this site.

At Surtsey, effusive lava activity continued in the western crater until 17 May 1965, so that gradually a flat lava shield was formed southwards from the crater, while foreset-bedded breccia was produced by submarine flow. The lava shield was gradually stacked to a height of 100 m above sea level.

On 22 May 1965, explosive activity again made itself apparent above the sea floor about 600 m east-northeast of Surtsey, creating this time a small tephra island, Syrtlingur, which climaxed at a height of 70 m and a maximum area of 0.15 km^2. Since no lava was emitted to harden into armour, this island was washed away by wave action a few days after the eruption ceased, i.e. on about 17 October 1965. Yet another island of tephra, Jólnir, was created by explosive submarine activity starting 800 m southwest of Surtsey on 26 December 1965. At its maximum, this island had a height of 70 m and an area of 0.28 km^2. The eruption died out on 10 August 1966 and Jólnir had disappeared in late October the same year.

Soon after the Jólnir activity died out, lava

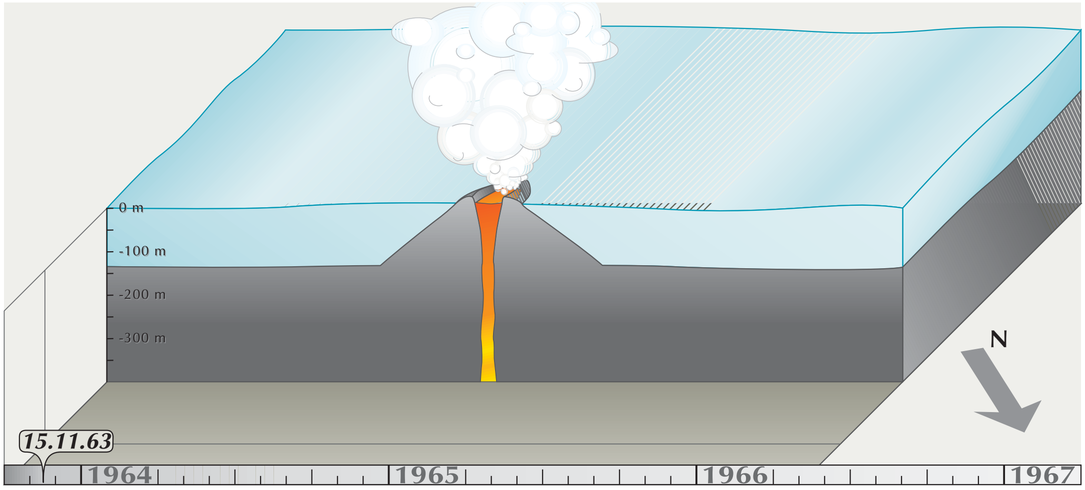
Lava effusion on Surtsey, April 21, 1964. (Photo: Garðar Pálsson).

The eruption column of Syrtlingur in the spring of 1965 (Photo: Sigurður Þórarinsson).

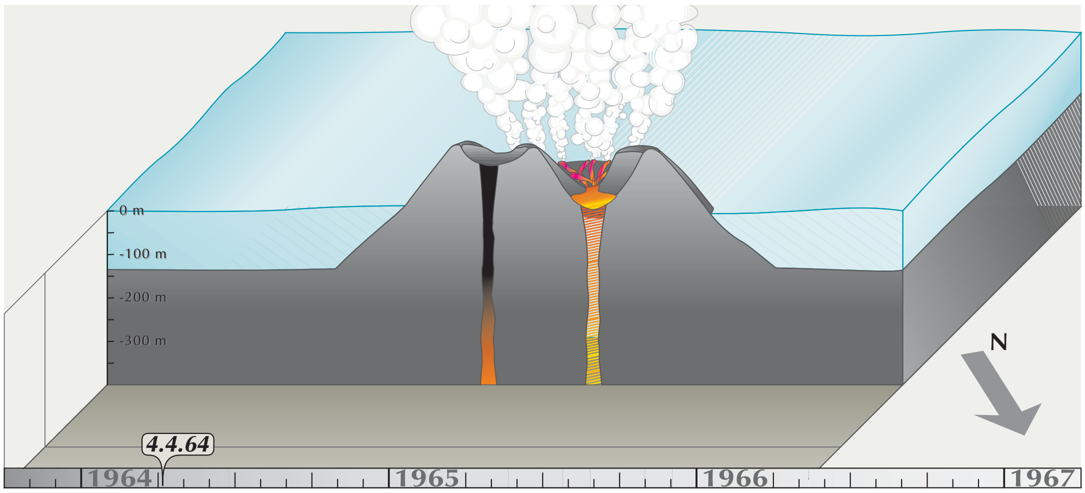
began erupting once more as a 220-m-long fissure opened on 19 August 1966 along the floor of Surtsey's eastern crater, Surtur, which had been inactive since early February 1964. Lava flowed incessantly from this fissure throughout late 1966 and early 1967, covering the landscape to the south and east and constructing the island's second lava shield. Between 12 and 17 December 1966, another fissure became active in the western inside wall of the eastern tephra crater, producing a small lava flow. Then, during the period of 1–8 January 1967, lava broke through the eastern tephra cone, Austurbunki, at four additional sites, but the southernmost eruption site is now covered with sand dunes. Lava was last seen to flow on Surtsey on 5 June 1967.

At the end of the eruption in June 1967, Surtsey had achieved a size of 2.65 km^2, and the total amount of eruptive material was estimated to be 1.1 km^3, about 70% of which was tephra and 30% lava. The height of the island at that time was 175 m above sea level, and as the sea water depth before the eruption had been about 130 m, the total height of the volcano was 305 m. A simplified geological map of Surtsey is shown in (Fig. 2.19), based on July 1967. As far as is known, the Surtsey eruption is Iceland's longest continuous volcanic eruption in historical times (i.e. since AD 900). For example, it can be compared with the Hekla eruption of April 1766 to May 1768 and the Tröllahraun eruption of 1862–1864, although several other historic eruptions have emitted greater volume than that of Surtsey.

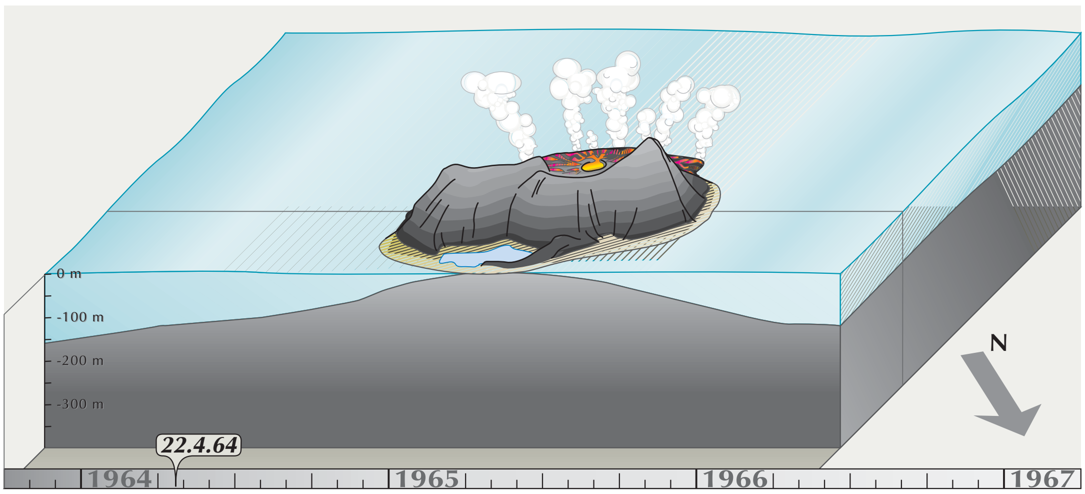
Steam rises from lava flowing into the sea. (Photo: Hjálmar R. Bárðarson 1967).



(A) 15 November 1963: the island of Surtsey emerges.

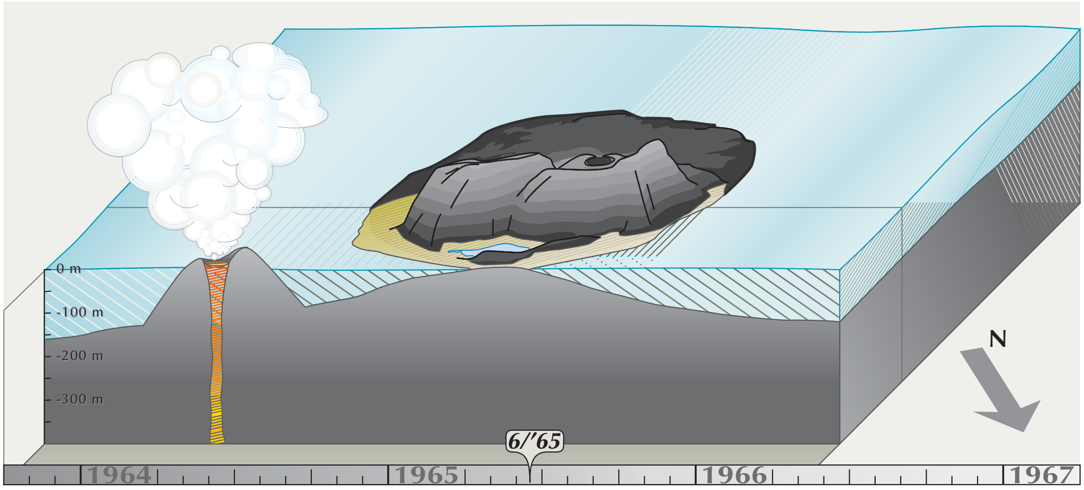


(B) 4 April 1964: the western crater (Surtungur) starts erupting lava.

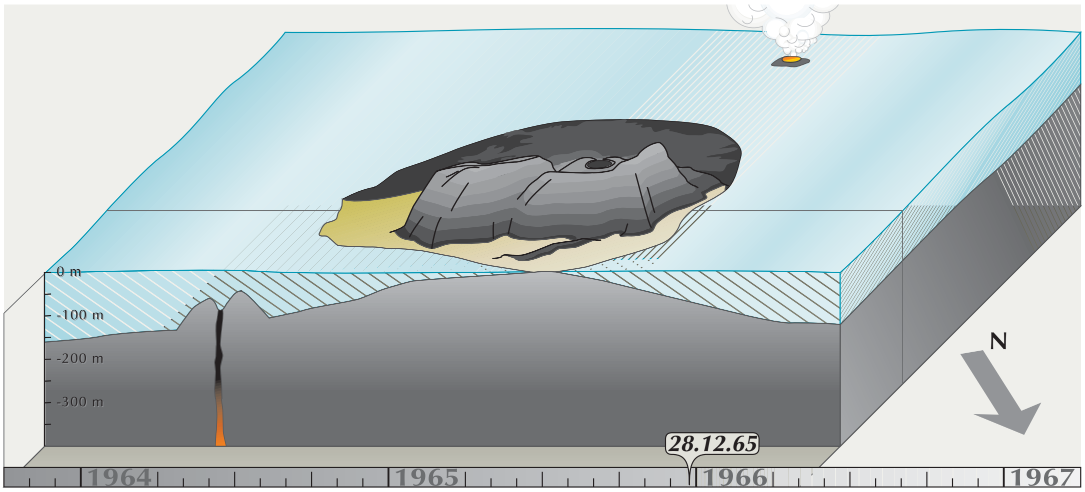


(C) 22 April 1964: the lava eruption at its maximum.

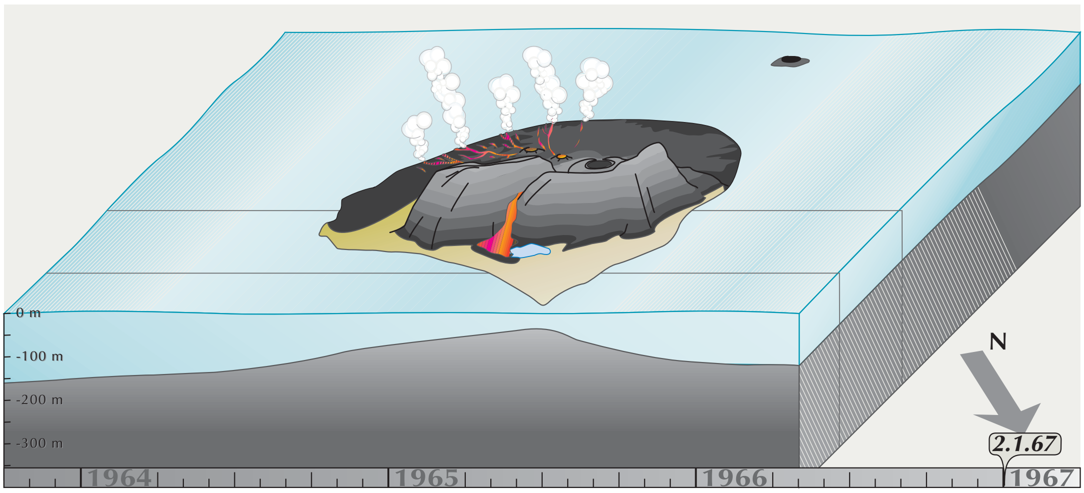
Fig. 2.18. Block diagrams illustrating the development of the Surtsey volcano, cf. Table 2.8.



(D) June 1965: activity on Surtsey has ceased temporarily and a new island, Syrtlingur, has emerged.



(E) 28 December 1965: the island of Jólnir emerges.

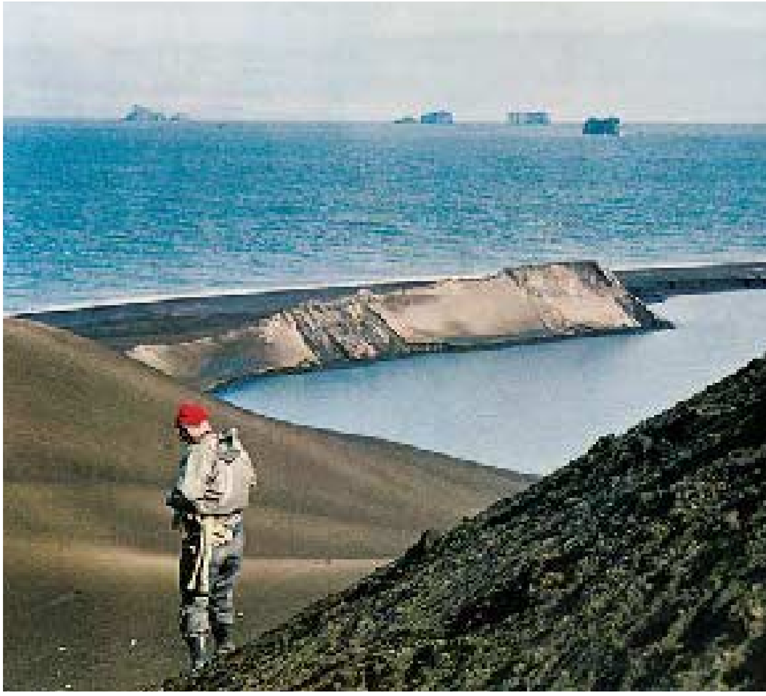


(F) 2 January 1967: Surtsey's last lava crater opens, after a renewal of activity on the island.

Research work

The Surtsey eruption immediately aroused a great deal of interest, both among scientists and the general public. As a spectacular eruption in the picturesque surroundings of the Vestmannaeyjar archipelago, it attracted many Icelandic and foreign visitors. The research value was further acknowledged by the scientific community after it became evident that Surtsey would prove lasting, because then it was clear that Surtsey offered an exceptional opportunity to study the development of an oceanic volcano from its inception on the sea floor, through the formation of an island, to the new land's modification by hydrothermal processes and wave abrasion. Scientists, including earth scientists and biologists, first stepped ashore on 16 December 1963. After that, numerous visits and expeditions to the island followed.

The course of this exceptional, many-faceted event was observed from the air as well as from surface elevations. Vertical aerial photographs were thus taken on 19 flights during the Surtsey eruption, in the period from February 1964 to March 1967. Such trips have continued since the eruption ceased and have now yielded 53 aerial photosets, most recently from August 2004. The photos overlap 60–80% and are of generally high quality; six are reproduced here in Fig. 2.20. This documentation of the construction and obliteration of volcanic islands is unique, with no comparable coverage existing anywhere else. In addition, several detailed topographic and bathymetric maps were compiled during and after the eruption.



Sigurður Þórarinsson, professor and volcanologist (1912–1983) at work in Surtsey on April 16, 1964. Surtsey lagoon and the Vestmannaeyjar archipelago is seen in the background. (Photo: Hjálmar R. Bárðarson).

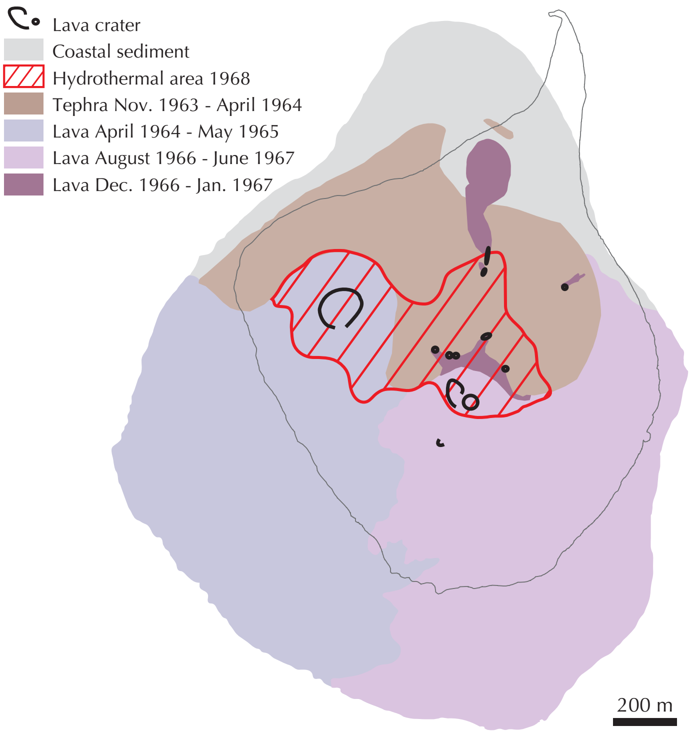


Fig. 2.19. Simplified geological map of Surtsey in 1967, with the approximate extent of the hydrothermal area indicated as it was in 1968.

Numerous geological and geophysical studies have been linked to the Surtsey eruption. Lightning activity, for instance, typifies subaqueous/subglacial eruptions, so during the Surtsey eruption, field and laboratory experiments were devised to elucidate the cause. The conclusion was that the contact of sea water with glowing lava at the vent led to charge separation, resulting in negatively-charged tephra and positively-charged steam. Lightning jumped between the oppositely charged clouds whenever the difference in voltage exceeded the insulating resistance of the intervening air (Sveinbjörn Björnsson et al. 1966; Blanchard and Sveinbjörn Björnsson 1967).

17 February 1964: hydromagmatic eruption in the western tephra crater (Surtungur). The eastern tephra crater has ceased activity and is partly filled by a pond.

2 October 1966: lava erupting from vents within the eastern tephra crater.

11 April 1964: lava erupting from the western crater. A lagoon has formed in the northern part of the island.

3 January 1967: lava erupting from five vents in the eastern tephra cone. The snow has melted in areas over subsurface heat.

23 February 1965: the eruption from the western crater has continued to build up a large lava shield.

18 July 1967: the Surtsey eruption has come to an end.

Fig. 2.20. Aerial photographs of the Surtsey eruption taken between 1964 and 1967, cf. Table 2.8. Published with permission of the National Land Survey of Iceland.

Physical conditions during the Surtsey eruption allowed the collection of the first-ever samples of volcanic gases virtually uncontaminated by atmosphere. Comparison with a mineralogical geobarometer showed the volcanic gas to have been in equilibrium with the magma from which it evolved (Guðmundur E. Sigvaldason and Gunnlaugur Elísson 1968; Sigurður Steinþórsson 1972; Symonds et al. 1994). According to radioactive geochemistry, the water content of the undegassed magma was 0.6%, which may be typical for alkali basalt (Sveinbjörn Björnsson 1968). Further examples of research which the eruption facilitated included measuring the lava for its temperature and viscosity, and conducting magnetic surveys on the entire island during its development.

Petrological and mineralogical studies of the tephra and the lava, ongoing until after the eruption ceased, demonstrated a striking chemical modification of the basalt magma as the eruption proceeded. This indicated a layered magma chamber beneath Surtsey, down in the lower part of the Earth's crust (Sigurður Steinþórsson 1965; Sveinn P. Jakobsson 1968; Furman et al. 1991).

Small-scale experiments with pumping seawater onto molten lava were conducted in Surtsey by Thorbjörn Sigurgeirsson in 1967. The purpose was to examine the cooling and hardening effect on the lava in order to verify whether lava flow could be systematically diverted, impeded or stopped. After a few hours of pumping on one side of a minor lava stream, it solidified and the flow was diverted to the other side. This experiment is considered to have been the first of its kind in the world. Drawing on the field observations at Surtsey, seawater was pumped on a large scale at Heimaey in 1973 so as to block or divert a lava tongue from Eldfell whose advance threatened to close the entrance to the Vestmannaeyjar harbour.

Volcanologists agree that for shallow waters the Surtsey event was the best-documented chain of submarine eruptions to date. It is especially noteworthy that the overall event provided scientists with the opportunity of observing four eruptions from their first visible beginnings. A particular geological focus was on the conditions under which the submarine eruption shifted to a subaerial eruption emitting lava. All things considered, the Surtsey eruption and the eruption products were studied with exceptional care, considering the methods and knowledge available at the time.

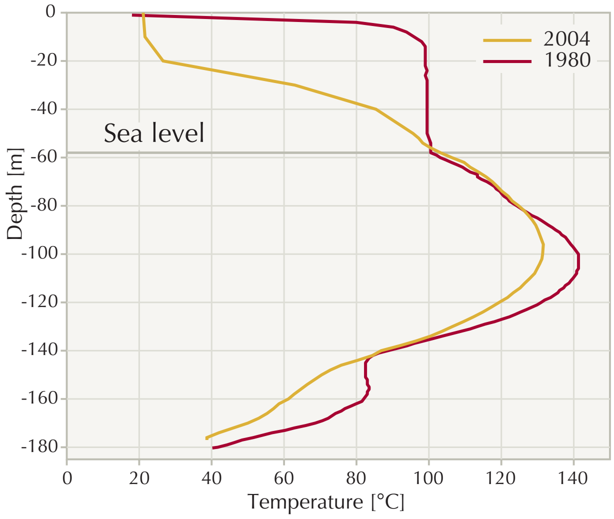


Fig. 2.21. Temperature measurements in the drill hole at Austurbunki as of September 1980 and August 2004. The seawater level is at a depth of 58 m.

Posteruptional history

Hydrothermal activity

The hydrothermal system on Surtsey, described in Chapter 2a, has been monitored and mapped every third year since it began to evolve. What made its development remarkable was how quickly tephra within the system was altered and consolidated into dense palagonite tuff.

Discovered by accident in the spring of 1967, Surtsey's hydrothermal anomaly had apparently not yet reached the surface by the summer of 1966, according to infrared air photos taken in August of that year. However, the anomaly was clearly noticeable in the eastern tephra cone through infrared aerial photos taken in August of 1968 (Friedman and Williams 1970, see Fig. 2.19). It has therefore been suggested that subsequent to lava extrusion, intrusive action occurred from December 1966 to January 1976 and led to the development of a hydrothermal system within the core of the eastern tephra cone (Sveinn P. Jakobsson and Moore 1986). Moreover, it appears possible that hydrothermal activity also occurred at some depth in the western cone, as a consequence of lava extrusion from April 1964 to May 1965. Characterised as “low-temperature”, this hydrothermal system is quite different from the well-known "high temperature" hydrothermal systems at the centre of many active volcanic systems.

The hydrothermal area at the surface continued to expand until approximately 1979, when it included segments of the western tephra cone, but then ceased to expand so fast, presumably because tephra consolidation had started to affect heat flux through the rock. Since about 1995, surface temperatures appear to have been on the decline. In the tephra cones, the highest near-surface temperatures within the hydrothermal area have typically measured about 100° C, indicating how vapour dominates the heat flux above sea level. Temperatures within the lava fields, especially next to the lava craters, have regularly declined after lava was extruded. By 1995 the lava surface generally conformed to ambient temperatures.

Temperature measurements have also been carried out on average every third year at Austurbunki, on the eastern border of the hydrothermal area, taking advantage of a 181-m-deep hole drilled in 1979 (Fig. 2.6). These measurements show a general regular cooling of the hydrothermal system deep inside the island (Sveinn P. Jakobsson et al. 2000), with the maximum temperature down at 104 m declining from a calculated temperature of 154° C in 1966 and 1967 to a measured temperature of 130° C in 2004. The general rate of cooling at the drill hole location is ≤1° C per year (Fig. 2.21). Monitoring will continue at the drill hole, providing the unparalleled opportunity of observing the evolution of a posteruptional mild hydrothermal system over time. It appears probable that similar hydrothermal systems developed at many of the Icelandic volcanoes which erupted subglacially during the Late Pleistocene.

Alteration of the tephra

The hydrothermal activity caused the Surtsey tephra to alter rapidly. In fact, palagonite tuff was observed at the surface in September 1969, at the southeast corner of the eastern tephra cone (Sveinn P. Jakobsson 1972). Upon this discovery a monitoring programme was established, measuring areas of tephra and tuff on average every third year (Sveinn P. Jakobsson 1978; Sveinn P. Jakobsson et al. 2000). Each time, rock samples have been taken and a new map prepared to show the expanding area of palagonite tuff.

The palagonitisation and consolidation rates of the Surtsey tephra were estimated on the basis of surface observations in 1969–1976 (cf. Fig. 2.22). Compiled for 11 localities where the temperature was considered to be roughly constant during that period, the results indicate that at 100° C (referring to the greater part of the tephra pile lying above sea level) it takes one to two years for the tephra to convert into dense palagonitised tuff, with a volume of over 10% palagonite. Furthermore, the results point to the rate of palagonitisation falling considerably when temperatures drop below about 40° C (Sveinn P. Jakobsson 1978). Fig. 2.6 shows the stage of tuff expansion in 2004.

The 1979 drill core (Chapter 2a) provided additional information on the nature of basaltic tephra conversion. Between 1967 and 1969, hydrothermal temperatures ranged from 40° C to 154° C in the drill hole section. The outcome over the following 12-year period till 1979 revealed that above 100° C, more than 90% of the original basalt glass had been palagonitised.

By 2004 some 55% of the exposed tephra had been transformed into palagonite tuff (Fig. 2.6). However, as the tephra that still remains unaltered constitutes only a relatively thin blanket encircling the tuff segment of the Surtseyan surface, it is estimated by volume that some 85% of what is left above sea level from the original tephra pile has been converted to palagonite tuff. Field observations allow the inference that the core of tuff now represents an area of 0.4 km^2 at sea level.

So far, tephra outside the hydrothermal area has not been observed to convert at all. In fact, comparison with other Icelandic tuff localities implies that conversion into palagonite takes thousand of years at the ambient weathering temperatures of this country. For Vestmannaeyjar, mean monthly air temperatures lie between 2° and 10° C, although diurnal and seasonal variations can reach twice this value.

Studies of the Surtsey material demonstrated for the first time (Sveinn P. Jakobsson 1972, 1978; Fisher and Schmincke 1984) that the palagonitisation process is posteruptional, occurring at low pressures and at relatively low temperatures, mostly under 100° C. A further

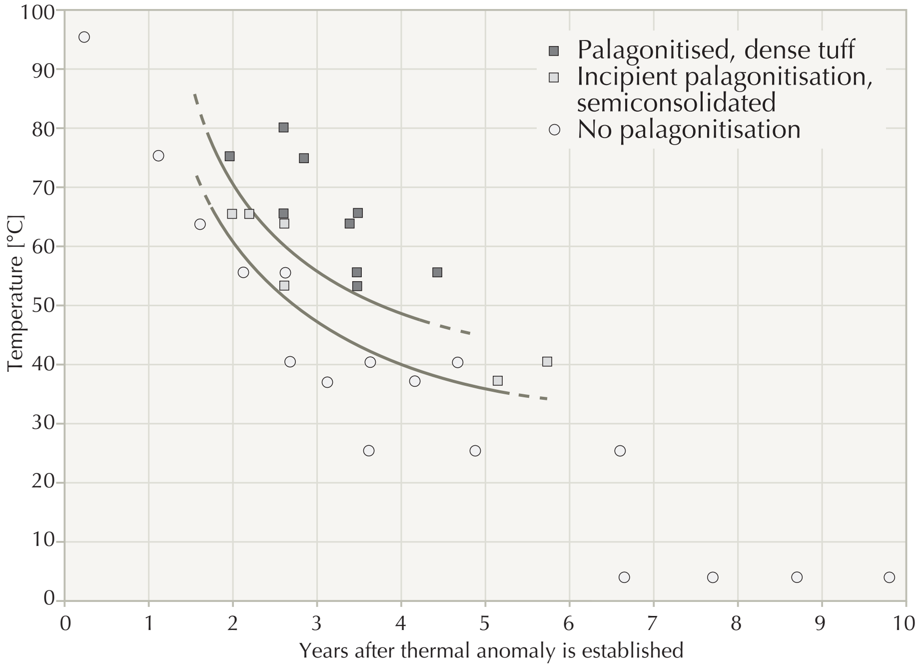


Fig. 2.22. Rate of palagonitisation and consolidation at the Surtsey surface as a function of temperature and time, based on surface observations at 11 locations between 1968 and 1977 (Modified from: Sveinn P. Jakobsson 1978).

discovery was that the process is highly temperature-dependent and can potentially proceed much faster than anyone had envisaged. In short, Surtsey offers a well-documented case on the consolidation and alteration of basaltic tephra in nature – a case that remains unparalleled.

Wind and water erosion

Wind was freely eroding Surtsey's tephra cones even before the eruption was over. Their slopes have also been subject to mudflow and solifluction (Sigurður Þórarinsson 1966, 1968; Calles et al. 1982). Although Surtsey thus offered an outstanding example of the interaction between erosion and deposition in an environment of strong winds and heavy rainfall, these processes were not fully monitored from the start. The tephra cone rims were estimated in 1980 as having been lowered by 1.5–2 m due to wind erosion (Ólafur Ingólfsson 1982) and by 2004 as having been lowered over 4 m. Aeolian action may have removed some 10 m (vertical thickness) of tephra from the central inner slope of the eastern cone. Although much of the eroded tephra was carried into the sea, the remainder was deposited along the flanks of the two cones and on the lava field. The extensive erosion of tephra by water has been photographically documented on the northern slopes of Austurbunki and Vesturbunki since 1985.

Reduction by coastal erosion

As mentioned in Chapter 2a, Surtsey was sometimes heavily eroded by sea waves during the eruption. Though the ease with which tephra erodes surprised no geomorphologist, the speed at which lava was abraded came quite unexpectedly. At times, a storm of only a few days would suffice to transform a coastline of gently-sloping, newly-formed lava into sea cliffs several metres high, footed with beaches of rounded boulders (Sigurður Þórarinsson 1964, 1966, 1968).

During the winter of 1963–1964, an exceptionally rapid retreat was observed in the lava cliffs on the southern coast, which receded a maximum of 140 m and an average of 40 m (Norrman 1970; 1980). Clearly Surtsey would not have survived such fast marine abrasion for more than a few years after the end of the eruption, if subaerial lava had not flowed over and protected the southern area of the volcano. Not only did this serve to fortify the subaerial tephra and reduce erosion rates, it also enlarged the island considerably.

The posteruptive period has offered unique opportunities to study erosive forces in a coastal environment of strong wave activity (Norrman 1980, 1985). Moreover, fine coverage by vertical aerial photography enables meticulous research into the island's shrinkage through marine abrasion (Williams 1983; Sveinn P. Jakobsson et al. 2000; Garvin et al. 2000; Daði Björnsson 2004).

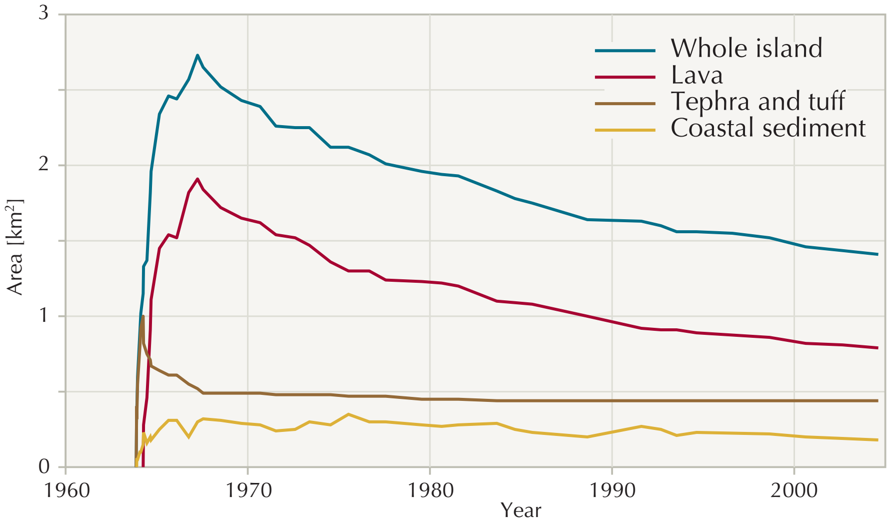


Fig. 2.23. Areal changes in Surtsey and its three principal geological formations, 1963–2004 (in km²). The measurements are based on aerial photographs on a scale of 1:5,000. Aerial measurements during the eruption, 1963–1967, were made by Sigurður Þórarinsson (1966, 1968).

Surtsey's three principal geological units – tephra, lava and palagonite tuff – react quite differently to such abrasion. Fig. 2.23 shows the cumulative areal modification of Surtsey as well as distinct changes in each of these three units during the island's construction period, 1963–1967. The subsequent depletion after eruptions ceased in 1967 is also shown, with the diagram demonstrating that lava erosion is the most important factor in island reductions. The coastal sediment on the northern spit undergoes perceptible variations in area, probably depending primarily on winter storm intensity, but was in general seen to diminish slightly during the period.

Figure 2.24 shows how the Surtsey outline changed from 1967 to 2004, as the surface area shrank from a maximum of 2.65 km² in 1967 to 1.41 km² in 2004. Marine abrasion appears likely to proceed at a considerable rate until the resistant core of palagonite tuff, the volcanic necks, and the lava that overlays tuff have been exposed on every side. Marine abrasion wore its way to the palagonite core at the western cliffs as early as 1985; when this core has been reached on other sides, erosion will subside considerably.

Submarine erosion

As was mentioned previously and summarised in Table 2.8, eruptions occurred at three points on the seabed apart from Surtsey itself.

Bathymetric maps of the Surtsey surroundings were prepared on nine occasions, from 1964 to 2000, (Norrman 1970; Sveinn P. Jakobsson 1982; Norrman and Erlingsson 1992; Icelandic Maritime Administration 2002) and demonstrate considerable changes in the submarine environment (Fig. 2.25). During this time the Surtsey platform was widened considerably, due to beach material deposited from the island. These bathymetric maps also reveal that Surtla and the submarine remnants of Syrtlingur and Jólnir islands have suffered constant, rapid erosion, probably caused by both wave action and bottom currents (Fig. 2.26).

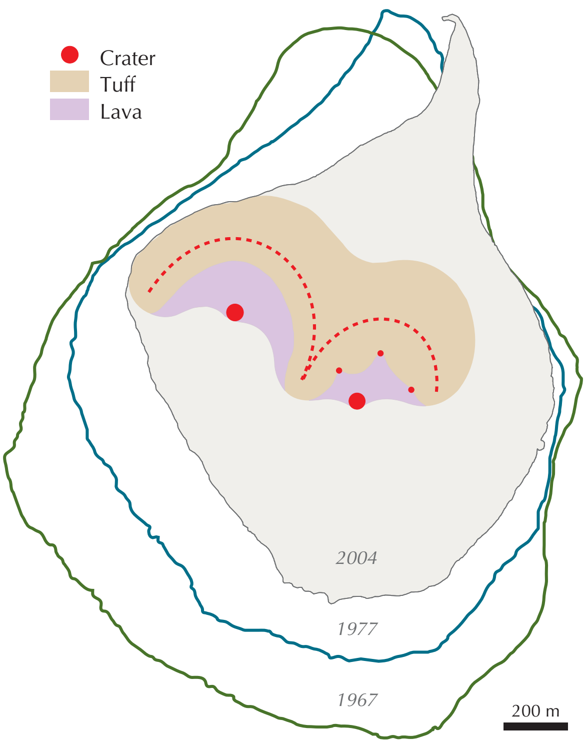


Fig. 2.24. Changes in the shoreline of Surtsey between 1967 and 2004. The estimated extent of the central core (about 0.4 km²) is indicated, consisting of palagonite tuff (brown), craters (red) and lava resting on tuff (violet).

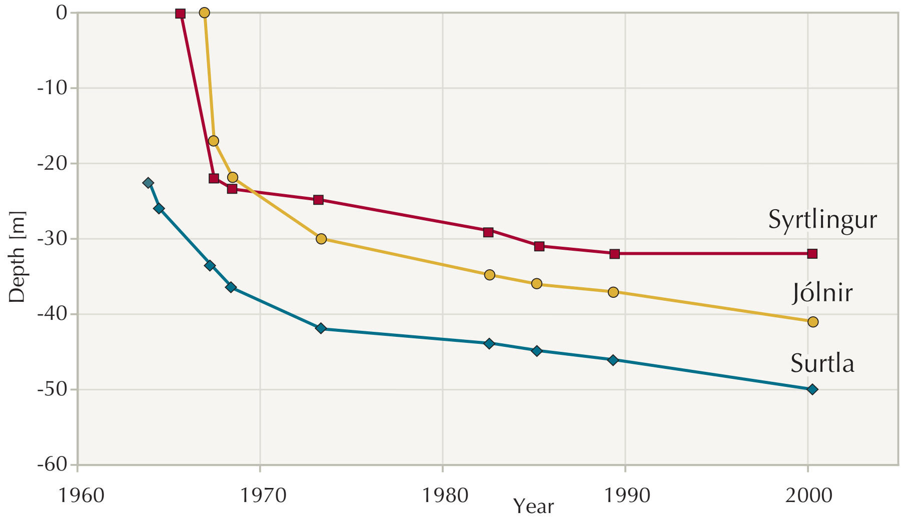


Fig. 2.25. Abrasion of the seamounts Surtla, Syrtlingur and Jólnir, with reference to the mean depth of the top platform.

In 2000 Surtla still stood 70 m above the surrounding sea floor, having been lowered by some 30 m, while the depths to the the top of the former islands of Syrtlingur and Jólnir was 32 m and 41 m, respectively. Since data show the rate of erosion to be decelerating, these submarine hills seem likely to survive far into the future. The possible development of palagonite tuff in the cores of these seamounts would hinder erosion appreciably. However, data from the Surtsey volcano shows a particularly fast, steady rate of erosion of submarine volcanic deposits, unlike anything that has been monitored previously. No comparable information has come to light elsewhere.

Future development of Surtsey

The curve of cumulative areal change in Surtsey is fairly regular (Fig. 2.23), which facilitates the prediction of future developments. Island erosion has thus been modelled by using a cone to approximate the shape of Surtsey and assuming the rate of erosion to be proportional to coastal length (Sveinn P. Jakobsson et al 2000; Sveinn P. Jakobsson and Guðmundur Guðmundsson 2003). The estimated parameters of the model were based on observed values, which resulted in the extrapolated curve coinciding with the area of the palagonite core (0.4 km^2) about 160 years after the end of the eruption (Fig. 2.26).

When the core of the Surtsey volcano has been reached, the island will resemble some of the islands and sea stacks of the Vestmannaeyjar archipelago, especially Bjarnarey and Elliðaey (Fig. 2.4). These two islands, dated by tephrochronology to be about 6,000 years old, were formed in the same manner as Surtsey. The comparison enables us to predict that Surtsey will survive for a long time, probably for thousands of years.

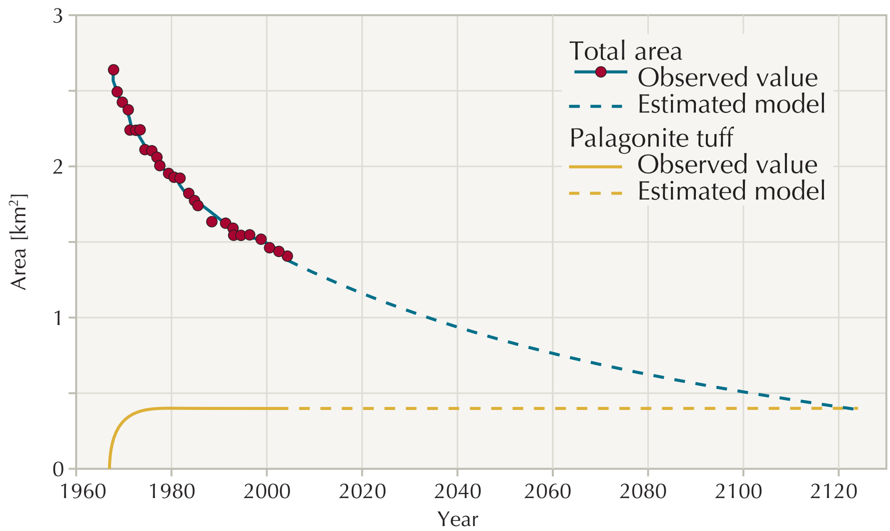


Fig. 2.26. Observed changes in the area of Surtsey since June 1967. The prediction model and estimated developments in the palagonite tuff core are also shown. The model predicts that about 160 years will elapse from the end of the eruption until only the palagonite tuff is left above sea level.

Sea rocket was the first plant species to colonise Surtsey in 1965. Its seeds were dispersed by sea and washed upon the shore of the island (Photo: Sturla Friðriksson 1966).

History of life

Influx of terrestrial organisms

The appearance of Surtsey provided a unique biological opportunity to study the colonisation and succession of life on a sterile island surface. By 1965, the island was already protected by law, with strict visitation restrictions to ensure that no plants or animals would be transferred to the island by humans. Due to this foresight among Icelandic scientists and the authorities, species colonisation and ecosystem development on Surtsey has occurred without human interference. In particular, the study of plant colonisation has revealed that ocean currents, winds and birds are the leading agents in transporting new species to the island.

Dispersal by sea

In 1964, during the first spring after Surtsey rose from the sea, seeds and other plant parts were discovered that had washed onto the freshly-formed shore. Some of these seeds were collected and found to germinate in the laboratory (Sturla Friðriksson 1966b). This was an early evidence that seeds carried by ocean currents would prove to be the first pioneers. In the spring of 1965, close to the shoreline, the first vascular plant seedling was discovered, the sea rocket *Cakile arctica*. Other coastal species, such as the sea sandwort *Hockenya peploides*, lyme grass *Leymus arenarius* and oyster plant *Mertensia maritima*, soon followed this pioneer. Occasionally a few plants of the long-stalked orache *Atriplex glabriuscula* have also been observed growing in the drift line. The seeds of these pioneering coastal species are rather large,

Tea-leaved willow provides an example of a species which has been dispersed by wind to Surtsey. (Photo: Erling Ólafsson 2005).

float easily and tolerate the salty seawater, adapting them very well to sea transport, which is their main route of long-distance dispersal. Probably the island's pioneers originated from parent plants growing on the sandy shores of Heimaey or along the southern coast of Iceland, where they are abundant. The distance from Surtsey to Heimaey is 18 km, while 32 km separate Surtsey from the mainland.

Seeds have also been dispersed to Surtsey by being attached to drifting materials. Living plant parts and small animals have been carried to the island on floating driftwood, clumps of grass turf and root tangles from nearby islands. Even skate eggs have been found washed up on shore with numerous plant seeds attached to their surface (Sturla Friðriksson 1975).

Dispersal by wind

Seeds and fruits from plants that are adapted to wind dispersal, such as cotton grass *Eriophorum* spp. and groundsel *Senecio vulgaris*, have frequently been found on Surtsey during the latter part of summer when the wind blows off the mainland to the island; however, neither of these species has yet been found growing on the island. Other species adapted to wind dispersal, such as the dwarf willow *Salix herbacea*, woolly willow *Salix lanata*, tea-leaved willow *Salix phylicifolia*, dandelion *Taraxacum* spp. and autumn hawkbit *Leontodon autumnalis*, have become established on Surtsey and have most likely been carried there by the wind.

Scurvygrass on Surtsey, a common species of seabird cliffs and colonies in Iceland. The species was initially found at roosting sites of seagulls, which probably were the dispersal agents. (Photo: Erling Ólafsson 2004).

Mosses, lichens, fungi and algae reproduce by tiny spores and fruiting bodies that are picked up by air currents and dispersed by the wind. It seems obvious that the majority of species in these groups have been brought to Surtsey by air currents, since their scattered, widespread distribution at sites offering favourable growing conditions strongly implies this type of transport.

Dispersal by birds

It is a well-known fact that birds serve as seed carriers. Many bird species eat berries or fruits that contain seeds, only to expel them later as waste in new locations. Seeds can even end up in a bird's digestive tract when it consumes prey. In addition, seeds may stick to birds and fall off at far-removed locations. Similarly, the spores and soredia of rock lichens may remain externally on a bird's feet as it flies from one roosting site to another. Finally, birds carry nest building material from plants over significant distances.

There is considerable evidence of birds having carried seeds to Surtsey. Several migratory species use it as a resting spot on their way from the rest of Europe over the Atlantic. In the late 1960s, a study of the digestive tract contents of migrating snow buntings *Plectrophenax nivalis* revealed intact seeds, indicating long-distance dispersal (Sturla Friðriksson and Haraldur Sigurðsson 1969). Scurvygrass *Cochlearia officinalis* became an early colonist of Surtsey and was first noticed at a point where seagulls rested. In addition, the lichens *Xanthoria candelaria*, *Caloplaca verrucu-lifera*, *Lecania subfuscula* and *Lecanora polioph-aea* were first discovered at sites frequented by birds, since they are partly nitrophilous and are all commonly found along coastal cliffs where birds rest and excrete their droppings.

In the years following the establishment of a seagull colony on Surtsey in 1986, numerous new plant species colonised the island. The gulls probably carried nesting material to Surtsey from neighbouring islands, bringing with it seeds or other propagules of such plants as the crowberry *Empetrum nigrum*, meadow buttercup *Ranuncu-lus acris*, smooth meadow-grass *Poa pratensis*, Bering's tufted hairgrass *Deschampsia beringensis* and northern dock *Rumex longifolius*.

Arrival of marine organisms

The methods that marine organisms have for dispersing to Surtsey are probably quite numerous. Most algae, for example, have planktonic spores or zygotes that are transported by currents, while many marine invertebrates have planktonic larvae that likewise are spread by ocean currents. Such organisms can be distributed over relatively long distances.

Marine animal species with young that resemble the adult form rather than being planktonic are usually not dispersed by ocean currents. Colonising a new area can be difficult for such organisms, since they must crawl, swim or be carried to the new destination to be able to settle there.

Animals with sessile larval stages living on the seabed off Surtsey when the eruption began had an advantage compared to other benthic species, because they were able to colonise the new bottom substrate as soon as the eruption ceased. In November 1964, dredge samples from the base of the volcano, which lies at a depth of 100 m, included the swimming crab *Polybius holsatus*, aesop shrimp *Pandalus montagui* and brown shrimp *Crangon allmanni*. These species, as well as most of the other animals identified in the following years at the base of the volcano, were common in the benthos community immediately outside the area disturbed by the eruption.

In addition to the previously mentioned methods of dispersal, birds may have brought the spores and larvae of marine organisms in their feathers, as many seagulls and wading birds forage in the littoral zone. Drifted algae have regularly been observed on the shores of Surtsey, allowing the assumption that some algae populations have become established through drifted individuals. Moreover, some epiphytic animals were probably carried by drifting seaweed.

Plant colonisation and ecosystem development

1965–1974: The invasion of coastal species

During the first decade, 1965–1975, the sands and lava of Surtsey were extremely barren and nearly devoid of nitrogen in the soil. Shore plants, which characterised vegetation development during that decade (Figs. 2.27 and 2.28), together with a few moss and lichen species (see later), are among the few plants adapted to such nutrient-poor soils and harsh conditions.

The first vascular plant species found growing on Surtsey was sea rocket, in 1965. Moreover, it was observed again the following year, along with lyme grass, while oyster plant and sea sandwort lengthened the list in 1967 (Sturla Friðriksson 1970a). Among other plant species that managed to become established on the volcanic sands of Surtsey during its first decade were the curved sedge *Carex maritima*, which is likewise adapted to sandy environments, and scurvygrass, which grew poorly, obviously limited by the lack of nutrients (Fig. 2.29). The brittle bladder-fern *Cystopteris fragilis* was among the pioneers, managing to establish itself in moist, moss-covered crevices within craters and lava caves. Clearly, the spores of this species had been transported to the island by wind.

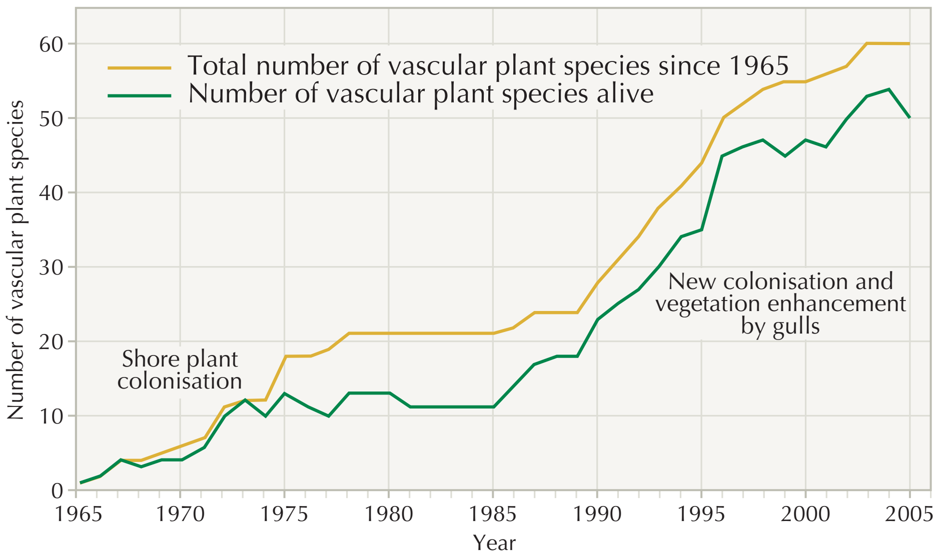


Fig. 2.27. Colonisation and survival of vascular plant species on Surtsey during 1965–2005.

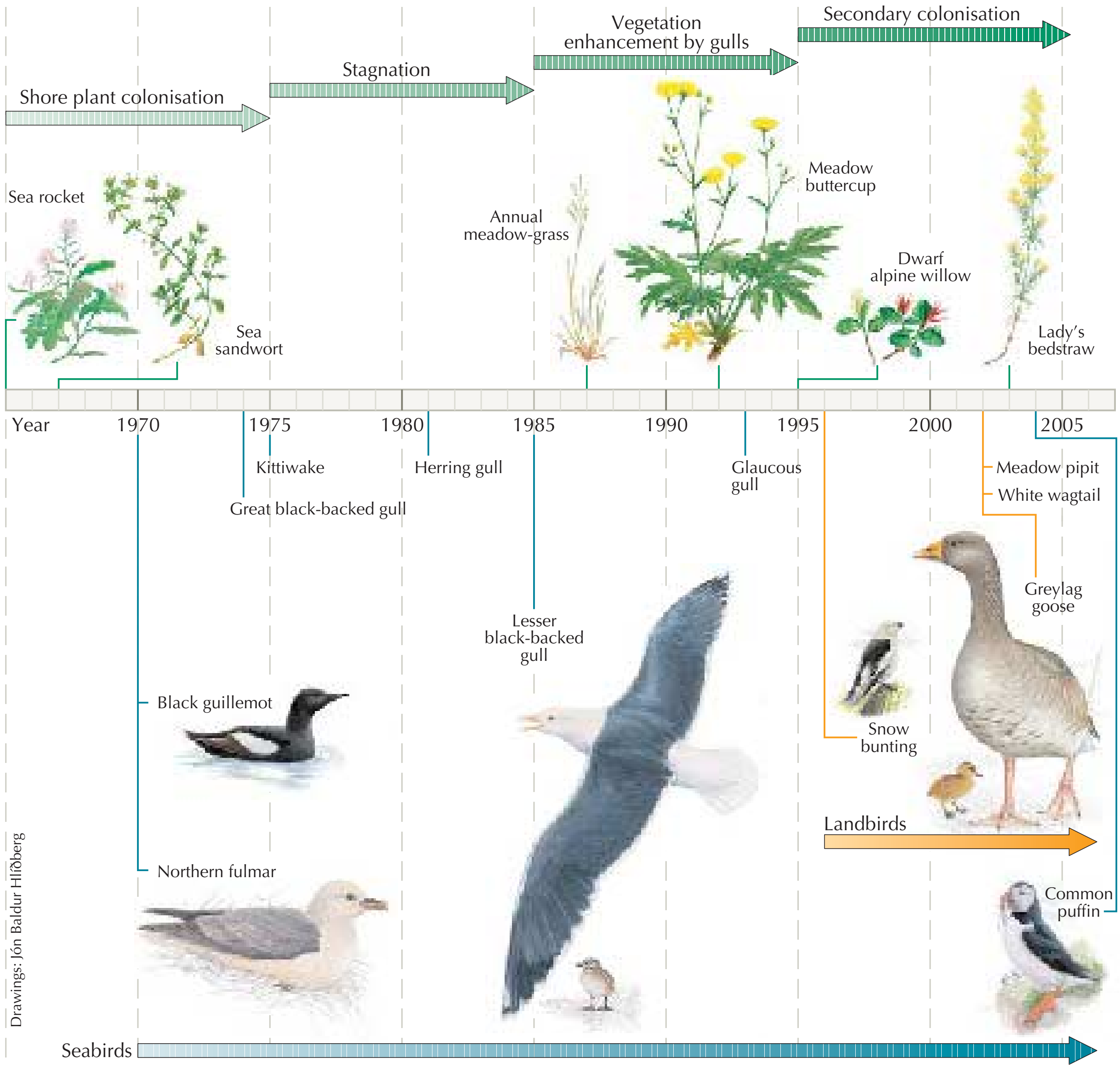


Fig. 2.28. Main steps in species colonisation and ecosystem development of plant communities and birdlife on Surtsey. A large increase in the number of breeding seagulls on the island after 1985 improved its nutrient status and enhanced development of its vegetation and invertebrate communities, enabling the first landbirds to settle on the island ten years later.

In 1974, at the close of the first decade of plant life on Surtsey, 12 species of vascular plants had been found on the island and 10 of them had become established (Sturla Friðriksson 1978). Species survival was thus relatively high for the initial period (Fig. 2.27).

1975–1984: Period of stagnation

After the momentous first decade, the rate of colonisation and succession stagnated. Although several new plant species were discovered on the island during the second decade, 1975–1984, very few became established (Fig. 2.27), probably due above all to the lack of essential soil nutrients. The sole new species managing to overwinter and to establish itself during this period were the common mouse-ear *Cerastium fontanum* and sheep's sorrel *Rumex acetosella*. Attempting but unsuccessful new species included the field horsetail *Equisetum arvense*, sea campion *Silene uniflora*, mountain rock-cress *Arabidopsis petraea*, common meadow-grass *Poa pratensis* and pro-cumbent pearlwort *Sagina saginoides*. However, all of these achieved greater success upon later attempts after growing conditions had improved.

The shore plants sea sandwort, lyme grass and

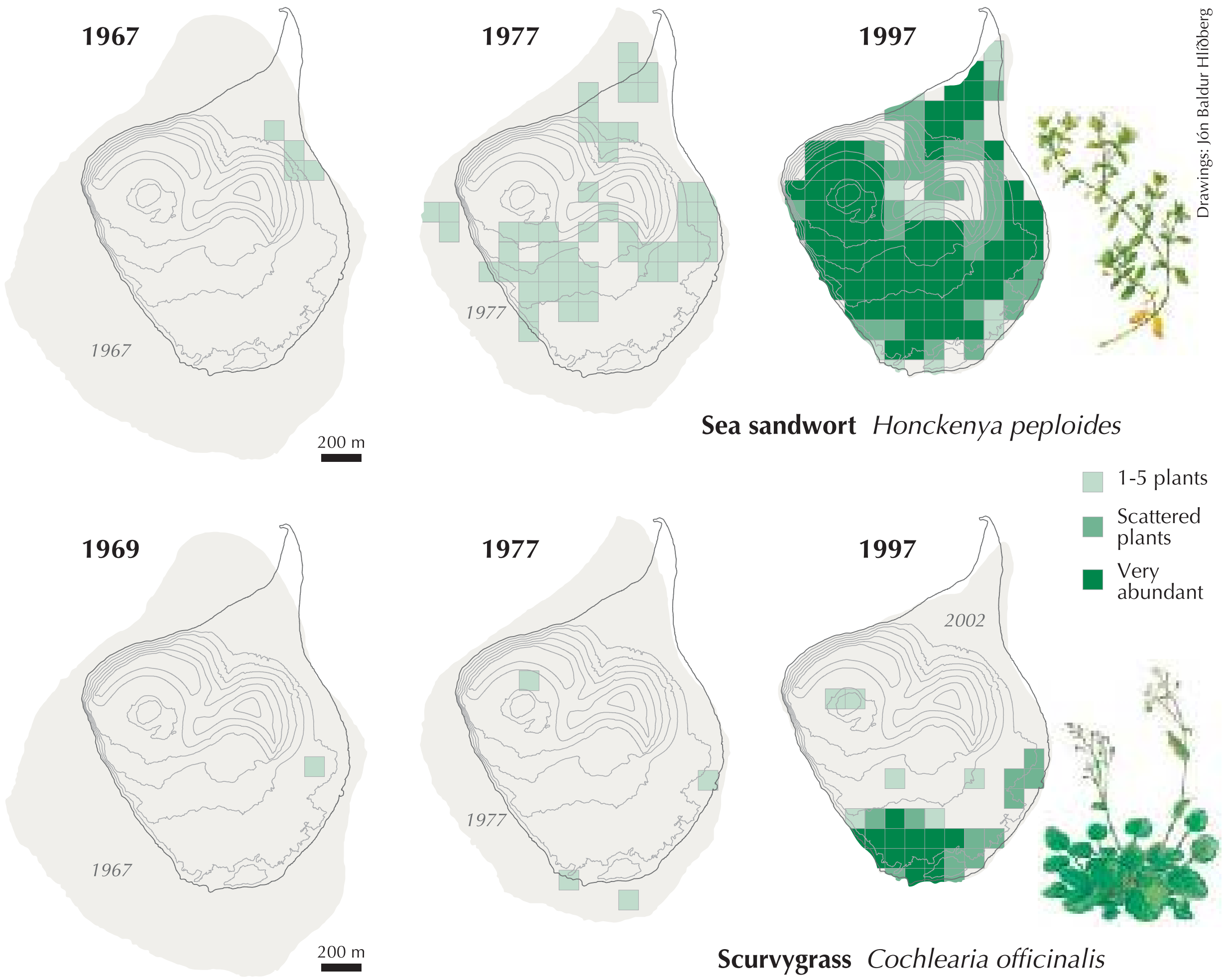


Fig. 2.29. Distribution of sea sandwort *Honckenya peploides* (a) and scurvygrass *Cochlearia officinalis* (b) on Surtsey in 1967, 1977 and 1997, shown on a 100 x 100 m grid of the island. The darker the colour the more abundant is the species. The sea sandwort was the most common plant on Surtsey in 1997 and is found on sand and tephra substrates throughout the island. The scurvygrass is more nitrogen dependant and first began to thrive after the formation of seagull colony on the southern part of the island.

oyster plant, not being as hampered by the poor soil conditions, continued flourishing and spreading during the 1975–1984 period. On the other hand, it was not until 1977–1979 that lyme grass and oyster plant began seeding and spreading effectively over the sand and pumice. Another landmark was that in the latter half of this period, the first plant community, composed of lyme grass, patches of sea sandwort and scattered oyster plants, formed on sand-covered lava in the eastern part of the island. Gulls became an important factor in this community, taking advantage of the developing lyme grass dunes, which were excellent sites for nest building and for sheltering their chicks. The plants in turn benefited from growth-enhancing nutrients introduced by the breeding gulls.

Similar stagnation was observed with regard to the lichens and mosses of the lava fields. The relatively quick colonisation by *Placopsis, Stereocaulon* and *Racomitrium* was followed by retrogression due to increased erosion, so that few additional species were discovered.

By 1984, the total number of vascular plant species found on Surtsey had increased to 21; however, only 11 of them had managed to become established (Sturla Friðriksson 1992) (Fig. 2.27). Hence, the relatively successful colonisation period of 1965–1974 was unexpectedly followed by much poorer survival

Sea sandwort, the first plant species to overwinter on Surtsey soon began seeding and spreading extensively. (Photo: Erling Ólafsson 2005).

Ripening seed capsules on a Surtseyan specimen of sea sandwort. (Photo: Erling Ólafsson 2004).

during 1975–1984. A whole new picture was emerging of biological colonisation and succession processes on new insular terrain.

1985–1994: New wave of colonisation and succession, facilitated by breeding gulls

The avian impact on vegetation development remained limited throughout the island's first two decades. Breeding birds were relatively few and their nests mostly confined to the sea cliffs. In 1986, the first sign of a seagull colony, consisting of 10 nests built by lesser black-backed *Larus fuscus* gulls and herring gulls *L. argentatus*, was noted on the black, barren lava in the southern part of the island. A sharp increase in the breeding population followed, with the number of nesting pairs reaching 180 by the summer of 1990, when great black-backed gulls *L. marinus* were also breeding in the colony. Concomitant to the population explosion of gulls was a new wave of plant colonisation and succession; the stagnation characterising previous years was finally broken. Not only were a number of new species discovered, but many of the species which had previously attempted colonisation without success reappeared. Most of this development took place within the gull colony (Borgþór Magnússon and Sigurður H. Magnússon 2000). Another change was a considerable improvement in species survival, against the previous period (Fig. 2.27). The rapid plant colonisation, vigorous vegetation succession and much improved plant survival now evidenced were clearly driven by the gulls. Apparently, they not only improved plant survival and growth by applying soil nutrients through their excreta and bits of lost chick feed, in addition to the decaying carcases of young and adult birds, but they also facilitated plant dispersal to Surtsey (Borgþór Magnússon and Erling Ólafsson 2003).

Several plant species, e.g. the sea-mayweed *Tripleurospermum maritimum* and scurvygrass *Cochlearia officinalis* (2.29b), Richardson's fescue *Festuca rubra* and common sea meadow-grass *Puccinellia coarctata*, having barely survived previously, were quick to take advantage of the improved soil nutrient condition by expanding their range on the island. Among the more important plant species taking a foothold during this period were smooth meadow-grass, annual meadow-grass *Poa annua*, common bent *Agrostis capillaris* and common chickweed *Stellaria media*. Within a few years, the centre of the gull colony had turned green with a continuous cover of vegetation, and a forb-rich grassland community had arisen on Surtsey.

Gulls also affected lichen colonisation on Surtsey, mainly in two ways. Firstly, soil formation around the breeding colony enabled the colonisation of such soil lichens as *Cladonia* spp. Secondly, nutrients introduced by the gulls provided the potential for a special crustose lichen community to colonise the lava rocks around the breeding colony, a community composed mainly of *Lecania subfuscula* and *Lecanora poliophaea* together with *Caloplaca verruculifera* and *Xanthoria parietina*.

By 1994, the number of higher plant species recorded on Surtsey had doubled (from 21 to 41) and the number of surviving species had tripled (from 11 to 34), which demonstrates the profound effects of the breeding gulls on plant colonisation and as well as plant survival (Figs. 2.27 and 2.28).

1995–2004: Secondary plant colonisation, first breeding by landbirds

The relatively high plant invasion rate continued between 1995 and 1999, with 13 new species recorded on the island. Then the invasion rate began to level off and no new plant species has been recorded since 2003. It thus appears that most of the species which can potentially benefit from the gull transport bridge and nutrient enrichment have already arrived.

An interesting aspect of the history of Surtseyjan flora since 1995 is the establishment of several secondary plant colonisers. They include three willow species: the dwarf willow, woolly willow and tea-leaved willow. In all likelihood, seeds of these three species were routinely dispersed to Surtsey by wind, but met with unfavourable conditions for their growth and development until the most recent decade. Improved nutrient status was probably also the main prerequisite for other recent plant colonisers gaining a foothold, such as the cold eyebright *Euphrasia wettseinii*, lady's bedstraw *Galium verum* and northern green orchid *Platanthera hyperborea*, which have all appeared within the gull colony since 2001.

The cold eyebright is a semi-parasitic plant that poaches resources from its host plants through root connections. While lady's bedstraw and northern green orchid are both common species on Icelandic grasslands and heathlands, they are never encountered in barren or extensively disturbed habitats (Hörður Kristinsson 1998).

By 2004, the number of vascular plant species that had been recorded on Surtsey reached 60. Of those, 54 still existed there, the highest number yet in that respect. By 2005, however, the number of species found dropped again to 50 (Fig. 2.27). Notwithstanding this temporary reduction, the number of species on Surtsey will probably rise somewhat over the next 40–50 years, after which it is expected to fall once more, because of ongoing erosion and island shrinkage.

Lady's bedstraw, a quite new coloniser of grass swards of the seagull colony on Surtsey, exemplifies the secondary plant colonisation that has occurred in the last few years. (Photo: Borgþór Magnússon 2005).

The great increase in plant diversity and cover subsequent to the gull invasion had profound effects on ecosystem development at Surtsey (Fig. 2.28). Insect life was enriched immensely, and in 1996 the first landbird was found breeding there: the snow bunting *Plectrophenax nivalis*, which feeds its chicks on flying insects. Snow buntings have bred on Surtsey ever since, in increasing numbers. Two passerines, the white wagtail *Motacilla alba* and meadow pipit *Anthus pratensis*, have also bred on Surtsey in recent years. Starting in 2002, a pair of greylag geese, *Anser anser*, bred on the island and still nests there. Thus the first vertebrate grazer has entered the young ecosystem evolving on Surtsey. The geese feed on the lush grass swards in the gull colony (Borgþór Magnússon and Erling Ólafsson 2003).

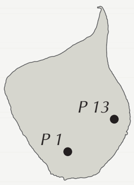
Birds can influence the development of vegetation in various ways. They may locally slow down succession through trampling, pulling out plants and scraping to build nests. On the other hand, the overall outcome considering nest materials, carcasses, food remains, pellets and other excreta, etc. has positive effects on the development of both flora and small fauna (see Erling Ólafsson 1982; Gjelstrup 2000). Nests, for instance, can be sources for seed colonisation,

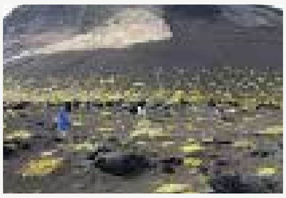
Effects of breeding gulls on ecosystem development

The effects of gulls on Surtseyjan ecosystem development have been studied with reference to permanent plots since 1990. In plots outside the gull colony, changes have proceeded very slowly, compared to plots within the colony. An example is given in the table below, which compare plant colonisation and succession along with several other parameters related to ecosystem development on the basis of two permanent plots that are located outside and inside the gull colony but otherwise represent similar tephra-covered lava. The measurements are taken from the 2004 survey.

In 1994, Plot 13 was delineated on the eastern part of the island, where plant succession has not been affected by gulls. The total plant cover increased from 1.7 to 3.1% from 1994 to 2004, but species richness and composition stayed constant throughout the period (sea sandwort, lyme grass and oyster plant). Thus it appears that by 1994 the plant community had already reached environmental barriers (e.g. nutrient status) determining plant succession.

Plot 1 was positioned in 1990 in an area where nutrient enrichment from the gulls was already evident. During the same ten-year period as above, plant cover increased from 28.5 to 98.8%, while species richness increased from 2 to 7; in this manner a barren, species-poor shore community with sea sandwort as the dominant species had changed to a closed forb grassland that was relatively rich in species. Nutrient input from the breeding gulls is without doubt the deciding factor for such rapid turnabouts.





Plots as photographed in July 2004	P13 – outside the gull colony	P1 – inside the gull colony
Plants:		
Species richness	3	9
Total plant cover %	3.1	98.8
Dominant species and cover %		
Honckenya peploides	2.1	25.6
Leymus arenarius	0.9	17.3
Poa pratensis		41.3
Plant biomass g dw/m^2	10.5	427
Soil*		
pH	7.73	6.81
C %	0.04	0.87
N %	0.006	0.067
Soil respiration μmol/m^2 s**	0.1	5.7
Insects:		
Species richness	12	22
Catch – specimens/day	19	176

*The soil was sampled in 2003, in order to analyse it for pH, C and N. **Bjarni Diðrik Sigurðsson, unpublished data

Results of the 2004 investigations into plant communities and biomass, soil chemistry and respiration, and invertebrate diversity and abundance in areas outside and inside of the gull colony on Surtsey.

and dead tissue provides food for small animals. Pulling out plants to build nests, in itself destructive, can in the final analysis be positive for ecosystem development.

Birds breeding on Surtsey clearly play a leading role in the formation of soil and the development of plant and insect communities there. This is especially obvious in the gull colony which provides an excellent research opportunity on the development of multi-species communities as well as the colony's interaction with vegetation and terrestrial invertebrate fauna. This gull colony is largely unaffected by humans, while elsewhere in Iceland gulls are generally persecuted.

Invertebrate colonisation

The first terrestrial invertebrate to be discovered on Surtsey was the midge *Diamesa zernyi*, in May 1964 (Oliver 1965). Further specimens were subsequently discovered, and by the end of the summer of 1965 seven additional invertebrate species had been found (Lindroth 1967). As might be expected, the initial visitors were mostly flying insects, which were brought by northerly winds from two main sources: the Icelandic mainland or other islands in the Vestmannaeyjar archipelago. Nonetheless, long-distance travellers, such as migrating moths and butterflies, were also recorded, carried to Surtsey by southerly winds from the European continent. For instance, a specimen of the non-native moth *Autographa gamma* was found on the island in 1965 (Lindroth et al. 1973). Even flightless invertebrates have been blown to the island by air currents, such as a small spider of the family Linyphiidae which was found in 1966 on northern Surtsey, after apparently gliding to the island on its long spinning threads.

Many invertebrates have been transported to Surtsey by the ocean, either with or without the aid of other drifting materials. Such specimens, both dead and alive, have been found on the beach after being washed ashore. The means of transport include driftwood and floating clumps of turf, which arrive on shore carrying numerous small invertebrates such as springtails and mites, as well as the sole proturan yet noted on the island. Birds have carried invertebrates not only in their plumage, but probably also with nesting

Of all the spider species that have reached Surtsey, *Erigone arctica* is by far the most common. Spider eggs are often found in clusters on the underside of stones and driftwood. (Photo: Erling Ólafsson 2004).

material. In fact, there are examples of species carried by birds migrating from Europe, viz. the well-known tick *Ixodes ricinus* and the blood-sucking hippoboscid fly *Ornithomyia avicularia* (Lindroth et al. 1973).

Although the number of invertebrates found on the island amounted to 136 species by 1970, only a few had managed to establish themselves under the hostile conditions prevailing on the harsh volcanic substrate. For the majority of species, colonisation was prevented by the lack of suitable food sources, meaning that species which proved capable of settling on the island had to depend on the organic matter washed ashore by the sea. Due to these reasons, the early settlers include the fly *Heleomyza borealis*, which breeds on fish and bird carcasses along the coast of Surtsey; the springtail *Archistoma besselsi*, which disperses by sea currents and colonises beaches all around Iceland; and the chironomid midge *Holocladius variabilis*, which breeds in shallow pools in the tidal zone (Lindroth et al. 1973). However, it was not until permanent vegetation appeared and a population of breeding birds was established on Surtsey that a local invertebrate fauna began to develop.

By 1974, nonetheless, a total of 170 species of terrestrial invertebrates had been identified on the

The carabid beetle *Amara quenseli* is common in Iceland, favouring open vegetation and sandy soil. The species was found in Surtsey as early as 1967 and is now found on sparsely vegetated areas throughout the island. (Photo: Erling Ólafsson 2004).

The common tortricid moth *Eana osseana*, whose larvae feed on grass, has found its ideal habitat in the gull colony. (Photo: Erling Ólafsson 2004).

island, equivalent to approximately 13% of the registered terrestrial invertebrate fauna of Iceland at that time. Furthermore, several species had become permanently established, forming a simple insect community composed of herbivores, saprotrophs and carnivores. By this time, a few scattered pairs of both great black-backed gulls and herring gulls had started to breed on the island. Each of the gulls' nesting sites, with accompanying plant growth, provided a base for the invertebrate community. Following the establishment of a distinct gull colony in 1985, vegetation and soil fertility underwent a dramatic change, while the number of soil and ground invertebrates, such as mites and springtails, escalated.

In the summer of 1993, the first earthworms were discovered, living in soil samples taken from the gull colony. These were juveniles of the chestnut worm *Lumbricus castaneus* (Hólmfríður Sigurðardóttir 2000). A survey of soil invertebrates in 1995 showed the number of mites to have climbed to a total of 62 species. Eight species of springtails were found, six of which were new to the island. Prior to 1995, a total of 16 species of springtails had been recorded, which means that only a couple of the original pioneers had been able to survive and establish themselves.

Although import of organisms has been strictly controlled, humans have brought at least two insect species to Surtsey: the lathridid beetle *Lathridius minutes* and the drosophilid fly *Drosophila funebris*, both found within the research station and shelter "Pálsbær" and no doubt coming as stowaways in food supplies.

Benthos colonisation

The first plants found growing on Surtsey were marine diatoms discovered in the coastal zone on recently formed lava in August 1964 (Sigurður Jónsson 1966). The annual number of benthic marine species observed around Surtsey rose rapidly from 1964 until 1970. Then the increase levelled off, and about 40 species of macroalgae have been recovered on each sampling occasion since 1977, with a similar pattern presented by benthic fauna (Erlingur Hauksson 1992b; Sigurður Jónsson and Karl Gunnarsson 2000) (Fig. 2.30).

Soon after the full cessation of volcanic activity, it became possible to observe distinctive communities. Sessile plants and animals were found growing on rocks in the sublittoral zone. At first only fast-growing opportunists, such as *Alaria esculenta* and *Desmarestia viridis*, were found in the summertime on larger stones. Vegetation

The slug *Deroceras agreste* was the first of two terrestrial molluscs found on Surtsey and was probably carried by birds. It is fairly common in the dense vegetation of the gull colony (Photo: Erling Ólafsson 2004).

The brown kelp species *Alaria esculenta* was among the first seaweeds to colonise the sublittoral slopes of Surtsey. The species was at first confined to the depth range 15 to 25 m. In recent years it grows most gregariously at 5–10 m depth (Photo: Karl Gunnarsson 1997).

remained scarce at first, confined to depths below 6 m and to boulders surrounded by sand and gravel. The highest plant cover occurred at depths of 15–20 m. A similar pattern was noted for benthic animals, whose dominant groups were hydroids and mussels. On the other hand, the cover and number of species grew fast until about 1971, when the number of species per sampling occasion started to level off. By that time a number of red turf algae had appeared, e.g. *Lomentaria orcadensis*, *Phycodrys rubens* and *Polysiphonia stricta*, while amongst invertebrates, the bivalves *Heteranomia squamula* and *Hiatella arctica* and crustaceans such as the acorn barnacle *Verruca stroemia*, the crab *Hyas coarctatus*, and shrimps had become common (Erlingur Hauksson 2000; Sigurður Jónsson and Karl Gunnarsson 2000; Aðalsteinn Sigurðsson 2000).

As the substratum has increasingly stabilised, especially at the east coast, the number of colonisers has climbed steadily. At depths of 0–15 m algae are dominant. With increasing depth, the cover of sessile animals becomes denser, whereas algae disappear below depths of 25–30 m (Sigurður Jónsson et al. 1987; Erlingur Hauksson 1992a).

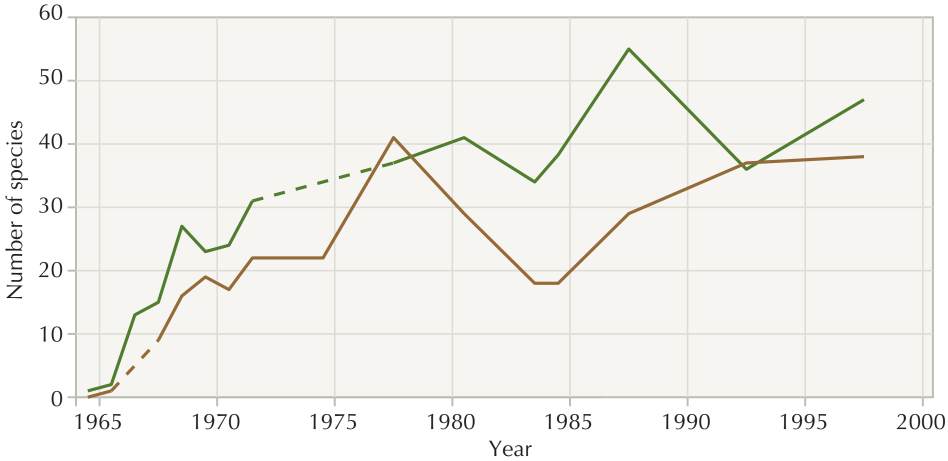


Fig. 2.30. Developments in the number of algae and animal species found in the Surtsey littoral and sublittoral zones on each sampling occasion from 1964 to 1997. Only groups monitored regularly are included, i.e. red, brown and green algae and the following animal groups: sponges, anthozoans, soft corals, molluscs, crustaceans (except amphipods), echinoids and ascidians.

Surtsey has offered a natural laboratory in geology, geomorphology and ecology. (Photo: Daníel Bergmann 2003).

3 Justification for inscription

3.a Criteria under which inscription is proposed

It is proposed that Surtsey, Iceland, be inscribed on the World Heritage List under Criteria viii and ix (cf. Article 11.5 of the Convention Concerning the Protection of the World Cultural and Natural Heritage and Paragraph 77 of the Operational Guidelines for the Implementation of the World Heritage Convention).

Criterion viii: *to be outstanding examples representing major stages of earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features.*

The IUCN has recently reviewed the role of the World Heritage Convention in recognising and protecting geological sites (Dingwall et al. 2005). This report examines the four different natural elements relevant to geological and geomorphological science. Three of these are relevant to nominating Surtsey for World Heritage status. Quotation marks and italics set off the IUCN text from this report.

a. Earth's history

'This subset of geological (as opposed to geomorphological) features are represented by phenomena that record important events in the past development of the planet. Sites in this category would be of outstanding universal value in exhibiting elements of earth history through rock sequences or associations rather than fossil assemblages.'

A relevant example mentioned by the report is the record of crustal dynamics and tectonism, linking the genesis and development of mountains and volcanoes.

In historical time, only a few volcanic islands have been formed in the world as a whole. Most of these islands have quickly disappeared and none has been as intensely investigated from its very beginnings as Surtsey. Thus Surtsey offers an outstanding example of a virgin volcanic island which is actively being created and shaped by geological and geomorphological processes.

The lava from 1967 on the northeast side of Austurbunki; erosion has revealed the feeder dike to the lava crater. (Photo: Sveinn P. Jakobsson 2002).

Finely bedded tuff at the crest of Austurbunki; erosion lines are brought out by the evening sun. (Photo: Sveinn P. Jakobsson 1998).

Lesser black-backed gull with fledglings on the southern lava of Surtsey. (Photo: Daníel Bergmann 2003).

b. Significant ongoing geological processes in the development of landforms

'This element of Criterion viii is the first of two aspects related to geomorphology and ongoing geological processes such as volcanic eruptions. It relates to active processes that are shaping or have shaped the Earth's surface.' Relevant examples mentioned by the report are volcanism and coastal or marine processes.

Surtsey is renowned for its contributions to science, especially the earth sciences. Research on the island during and since the eruption has provided invaluable information and insight into several major geological and geomorphological processes. The Surtsey submarine eruption (1963–1967) is the most exactly described submarine eruption ever. Studies on Surtsey have also demonstrated for the first time that palagonitisation is a posteruptional process and highly temperature-dependent. Finally, Surtsey has provided a rare chance to study the evolution of a posteruptional hydrothermal system.

c. Significant geomorphic or physiographic features

This second primarily geomorphological element represents the landscape products of active or past processes, which can be identified as significant physical landscape features. Relevant examples mentioned by the report are volcanoes, volcanic systems and oceanic islands.

Surtsey's subaerial geomorphology, i.e. its growth and erosion, has been thoroughly documented, through studies on site and through over fifty sets of vertical aerial photographs taken between February 1964 and August 2004. Thus it has been possible to map the erosion of the island, as well as its main geological features, in great detail and predict its future size. This applies not only to the supra-marine part of the island, but the entire volcano as its stands on the sea bottom. The data on submarine abrasion of two transient islets and one submarine ridge appearing during the Surtsey eruption is unique, with no comparable measurements existing on any other volcanic islands in the world.

Criterion ix: *to be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.*

Surtsey's emergence has provided a rare opportunity for studying one of the central questions of ecology: the dispersal and colonisation of sterile ground by plants and animals and the development of communities through the processes of succession.

The record of ecological research on Surtsey is remarkable in many ways: it spans 40 years of regular measurements; includes several decades of monitoring data on individual plant and animal species; allows a distinction between the arrival and establishment of a species; highlights how the interaction of birds, nutrients and plants impact primary succession; and provides a thorough census of an entire island. However, what truly makes Surtsey stand out in this regard, compared to similar areas of sterile ground where long-term measurements have been maintained, is how minimal the impact of humans has been.

3.b Proposed statement of outstanding universal value

Iceland and the Mid-Atlantic Ridge
Running from Jan Mayen to Antarctica, the Mid-Atlantic Ridge is the Earth's largest continuous geological structure. It was discovered in the 1950s and its discovery led, among other things, to the general acceptance of Wegener's theory of continental drift. Recently, a proposal was made to nominate the entire Mid-Atlantic Ridge for inscription on the World Heritage List.

An integral part of the Mid-Atlantic Ridge,

Surtsey in February 1964. (Photo: Sigurður Þórarinsson).

Iceland is also its largest supra-marine (aerial) component. The crest of the ridge, which marks the boundary between the North American and Eurasian tectonic plates, crosses the country from southwest to northeast, forming a major rift belt that expands continuously by accreting new land through volcanic activity. As one of the most volcanically active countries on Earth, Iceland is constructed almost exclusively of volcanic rocks.

Surtsey is the product of one of Iceland's 44 volcanic systems, the Vestmannaeyjar system. This is a young system comprising – if only what reaches above sea level is counted – seventeen identified Holocene volcanoes, which originally rose from the sea floor in the same manner as Surtsey. Two volcanic eruptions within this system during historical times are known with certainty: the Surtsey eruption of 1963–1967 and the 1973 Eldfell eruption on Heimaey.

Birth of an island

The formation of a new volcanic island is a rare event occurring somewhere in the global system of volcanic belts on the average of about twice a century. Most of these islands have disappeared quickly, and none has been as intensely investigated from the very beginning as Surtsey. This applies both to the eruption itself and to the posteruptional natural history of the island. In this regard, Surtsey has offered a natural laboratory in geology, geomorphology and ecology which has provided invaluable information on the creation and history of the Earth and its biosphere.

The Surtsey eruption immediately aroused avid interest among scientists and volcanologists agree that it is the best documented submarine eruption to date. It was a spectacular event in the picturesque surroundings of the Vestmannaeyjar archipelago. The scientific value of Surtsey was further acknowledged after it became evident that the island would perist and thus provide an exceptional opportunity to study the development of an oceanic volcano from its inception on the sea floor, through the formation of an island, to the modification of the newly erected structure by hydrothermal processes and wave abrasion. Surtsey is in reality the type locality of Surtseyan tephra (volcanic ash), produced by hydromagmatic (Surtseyan) eruptions. Surtsey is also the only well-preserved submarine tuya (tablemountain) on Earth.

Geological processes

Geologists are paying increased attention to the formation of palagonite tuff forms in Iceland, partly because similar formations are uncommon elsewhere on Earth. Studies at Surtsey demonstrated for the first time that the conversion of tephra into tuff is a posteruptional process, occurring at relatively low temperatures (usually below 100° C) and at low pressures. Furthermore, the process was shown to be highly temperature-dependent and to proceed much faster than anyone had envisaged. In 1969, two years after the eruption ceased, the first sign of palagonitisation was noticed at the surface of Surtsey. By 2004, some 85% of the tephra pile above sea level had been converted to palagonite tuff. In short, Surtsey has provided a well-documented case of the consolidation and alteration of basaltic tephra, a case which remains unparalleled.

Surtsey has provided a unique opportunity to study the evolution of a posteruptional hydrothermal system. This system, discovered at the surface of the island in the spring of 1967, has been monitored ever since. The hydrothermal area at the surface continued to expand until around 1979 but then the rate of expansion slowed down, presumably because the consolidated tephra inside the island had started to affect the heat flux. Since about 1995, Surtsey surface temperatures appear to have been declining by about 1° C annually. Data from Surtsey strongly suggests that the heat in the hydrothermal system had its source in intrusions which formed both below and above sea level from 1965 to 1966, in conjunction with lava extrusions.

Island erosion

The posteruptive period has offered unique opportunities to study erosive forces in a coastal environment of strong wave activity. The erosion of Surtsey has been documented in detail through an extensive series of vertical aerial photos. The three principal geological formations of Surtsey – tephra, lava and palagonite tuff – react quite differently to marine abrasion, with tuff proving the most resistant. Since 1967, surf has eaten away about half the island, above all loose tephra and lava. For the first few years, 3–20 hectares disappeared annually, while recent years have seen an annual average of approximately one hectare washed away.

The ongoing marine erosion of the coastline is a major natural force shaping Surtsey. (Photo: Torgny Nordin 2003).

An attempt has been made to model the future of Surtsey by combining data on coastal erosion (from 1967 to 2004) with data on the volumes and erosion rates of each of the different geological formations composing the island. These models indicate that 120 years from now, only the core of palagonite tuff will be left. Surrounded at that point by steep palagonite cliffs, Surtsey will be fairly resistant to further erosion and remain standing for thousands of years, like its neighbours in the archipelago.

A series of nine bathymetric maps compiled between 1964 and 2000 on the Surtsey environs reveal that the underwater remnants of the islets Syrtlingur and Jólnir have suffered continuous, rapid submarine erosion, caused probably by both wave action and bottom currents. Since the data indicate that the rate of erosion is gradually decreasing, these submarine hills should survive for a long time. The data on submarine erosion at Surtsey is a unique scientific resource, as no comparable measurements are available on any volcanic islands elsewhere.

Ecological laboratory

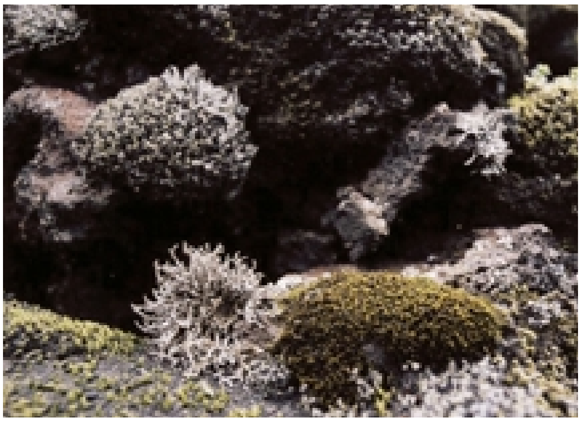
From its inception, the Surtsey island has been strictly protected, with human presence limited to a few scientists for a short period each summer. Rarely have the flora and fauna of an entire, intact and undisturbed island been recorded as they naturally accumulated, which means that Surtsey provides an exceptional opportunity to further our understanding of colonisation, extinction and the carrying capacity of an isolated, single-island ecosystem. Added to this are the prospects of studying species numbers declining as the island erodes and shrinks. The opportunity for direct testing of classic island biogeography concepts is invaluable and certainly seldom on offer. Already, monitoring individual plants during their colonisation of Surtsey has provided an extensive record of natural invasion processes and species dynamics; in future, this demographic data provides a foundation for further investigations, e.g. exploring secondary dispersal from the species that are now established.

Surtsey has already allowed the scientific world to gain insights into the interaction of species and how it affects ecological succession. The establishment of a gull colony in the mid-1980s, with its resulting nutrient input, altered primary succession in dramatic ways. The evolving sharp contrast between the lush,

The succession of plants on the sterile surface of Surtsey has been closely monitored from the very beginning. (Photo: Torgny Nordin 2002).

species-rich plant community inside the colony and the sparse vegetation outside has been better documented at Surtsey than at any other primary succession site in the world.

The pristine volcanic island of Surtsey is no mere scenario or model, but an actual, natural laboratory and a globally outstanding example of ongoing geological, geomorphological and ecological processes in the development of landforms and biological communities. Therefore, it is hereby proposed that this scientifically unique site be recognised through the award of World Heritage Site status.



Lichens and mosses were early colonisers of the Surtseyjan lava. (Photo: Hervé Jezequel 2005).

3.c Comparative analysis

Most recorded events of submarine eruptions have resulted in very short-lived islands, which frequently submerged quickly and became submarine volcanic shoals, although these could periodically re-emerge through repeated eruptions. When a more substantial island has resulted, as in Krakatau in Indonesia, human activity has soon affected development of the plant and animal communities, spoiling their usefulness for detailed, long-term research into the establishment and evolution of ecosystems in pristine island systems. Surtsey is therefore unique in both its persistence and its undisturbed environment, allowing a detailed record of geological development to be compiled along with biological surveys of ecosystem development.

Since its settlement around AD 870, 14 submarine volcanic eruptions are known to have occurred off Iceland, prior to the Surtsey eruption. Ten of these eruptions took place along the submarine Reykjanes Ridge, an extension of the Reykjanes peninsula in Southwest Iceland (Fig 2.3). Three of the eruptions there, i.e. in

1211, 1422 and 1783, are known to have built up islands. No eyewitness descriptions remain other than for the island first observed in May 1783, which was called Nýey ("New Island"). Reaching a diameter of at least 0.9 km, Nýey was apparently composed of tephra formed in a hydromagmatic eruption exactly like the first phase of the Surtsey eruption. Since no lava flowed, Nýey disappeared by autumn of the same year. It is considered likely that the Vestmanna-eyjar area had a submarine eruption in 1896. Four submarine eruptions have been documented off the north coast of Iceland (Sigurður Þórarinsson 1965).

Currently, thirteen sites are inscribed on the World Heritage List on account of their volcanic character, in addition to nine sites in which evidence of volcanism (usually extinct) is present (Fig. 3.1). Some of the listed sites, including Heard and McDonal Islands in the Southern Ocean, the Galapagos Islands in the Pacific Ocean, Aeolian Islands in the Mediterranean, Pitons Management Area on Saint Lucia in the Eastern Caribbean, and Hawaii Volcanoes National Park in the Pacific Ocean, are volcanic islands. However, with the exception of Krakatau, which lies within the World Heritage Site of Ujung Kulon National Park, none of these islands have appeared in recent historical times.

Below is a list of recent submarine eruptions and their products. Comparisons with Surtsey demonstrates that no other volcanic island shares its attributes (Table 3.1)

On 27 August 1883, the island of Krakatau in the Sunda Straits of Indonesia exploded with enormous force, so that all previous life is generally believed to have been extinguished, leaving a clean slate or *tabula rasa*. Just as in the case of Surtsey, the surviving islands were reshaped by the action of sea, wind and rain and were progressively re-colonised by plants and animals. The volcanology of Krakatau is well known, not least through pioneering work by the Dutch mining engineer R. D. M. Verbeekm, who undertook a series of investigations on the islands six weeks after the eruption. However, as there were no on-site witnesses of the Krakatau eruption, its basic features were only gradually clarified. Three years after the event, the first botanist arrived on Krakatau and collected 30 species of vascular plants that were already growing there. Within ten years, the islands were clothed with low-growing vegetation and today are covered with tropical rain forest, whose tallest trees are over 35 m high. This location is near the equator, in humid tropics with a mean annual temperature of 26.4° C, while Surtsey is in the cold-temperate North Atlantic. Furthermore, the reservoir of potential colonists in Java and Sumatra was much greater than in Iceland, which is itself still being colonised after the most recent Pleistocene glaciation (Thornton 1996).

Going farther back in time to 1831, the year that Darwin sailed from England, a submarine eruption in the Mediterranean Sea created a new island south of Sicily. In fact, the volcano there was surfacing for the fourth time since first being noticed during the Punic Wars (ca. 250 BC). As the first to go ashore, the British named the new site Graham Island, but not long afterwards the Italians landed and named it Ferdinandea. The French then named it Giulia, while the Spanish also showed an interest in claiming the new land. Fortunately, any further diplomatic wrangling was averted when the fragile island disappeared a year later through storm erosion. Graham Shoal is now a dormant submarine volcano lying about 10 m below sea level.

Location	Eruptions	Current status
Krakatau, Sunda Straits of Indonesia (Anak)	1927–present day	300-m-high volcanic island, visited by tourists and fishermen; no systematic scientific study
Fayal, Azores (Capelinhos)	1957–1958	Now joined to a larger island, with a loss of isolation
Surtsey, Iceland	1963–1967	Stable but eroding island volcano in pristine condition, under high levels of protection; ongoing, detailed research programmes in biological and geological sciences

Table 3.1. Recent volcanic islands and their status.

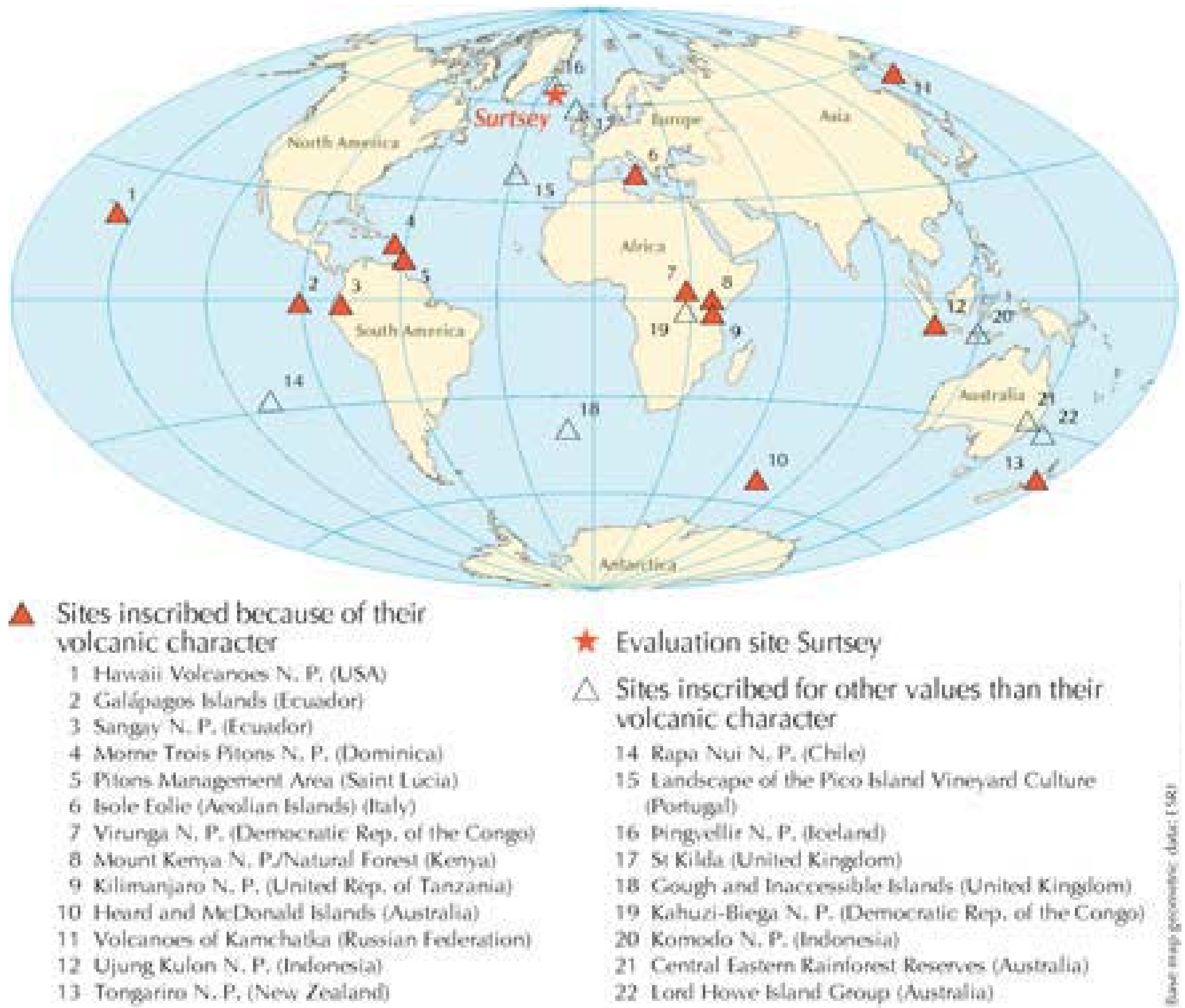


Fig. 3.1. A world map relating the nominated area of Surtsey nature reserve (red star) to World Heritage Sites, which are primarily inscribed for their volcanic character (filled red triangles) and sites where volcanism is present, although not the main reason for inscription (black, open triangles).

In 1927, a new submarine volcano raised itself above sea level within the Krakatau caldera. Named Anak, the resulting island grew quickly, due to repeated eruptions, and today stands over 300 m above sea level, with regular annual eruptions that produce mostly basaltic lava and scoria. Anak is not only of similar size, it has numerous other similarities as well to the island of Surtsey. However, significant differences exist respecting levels of investigation and the type of protection. While the geological, geomorphological and ecological development of Surtsey has been documented systematically and with great regularity, the formation and growth, erosion, biological colonisation and further aspects of Anak have been documented much more sporadically. In addition, while Surtsey has been effectively and totally isolated from casual visitors, tourism and development, Anak has experienced a steady stream of tourists, and local fishermen have set up camps there. Thus, unlike Surtsey, Anak is by no means a pristine laboratory for studying biological colonisation (Sturla Friðriksson and Borgþór Magnússon 1992; Thornton 1996).

In 1957 a volcanic eruption in shallow water began off the west tip of Fayal, an island in the Azores. Quite soon after the new island of Capelinhos appeared, it joined with the main island, and remained active until 1958. The volcanic process was very similar to that of Surtsey, but the geological formation and development as well as the biological colonisation of Capelinhos were poorly documented. Moreover, its biological isolation was broken as soon as it united with the larger island of Fayal.

A large number of the Earth's other submarine volcanoes are close to the stage of forming new islands; nevertheless, none of them have yet made the dramatic, permanent entry to the world above sea level that Surtsey managed in 1963. A few examples of ready-to-emerge volcanoes are given below:

- First noted by seafarers in 1851, Metis Shoal in the Tonga Islands of the South Pacific erupted in 1969 and built up a short-lived island. This island reappeared during another eruption in 1995. So far, volcanism has failed to establish a permanent island at Metis Shoal.
- Kavachi in the nearby Solomon Islands is the South Pacific's most active submarine volcano. While some of its eruptions, such as in 1939, have produced short-lived islands, its crater remains submarine to this day.
- Near Grenada in the Caribbean, the Kick'em Jenny submarine volcano, whose last eruption in 2000 brought it yet closer to the surface, still remains about 150 m below sea level.
- Loihi seamount in the Hawaiian Islands, considered by many as the next potential for an island in this volcanic chain, has a long way left before reaching the surface, as the crater still lies 1000 m below sea level.
- Ruby submarine volcano near Saipan in the Marianas Islands has now risen to within 230 m of the sea surface. First detected in 1966, Ruby erupted again in 1995.
- About thirteen active submarine volcanoes in the Izu and Volcano Islands of Japan are at a stage allowing them to form new islands. As an example, Fukutoku-Okanoba submarine volcano erupted last in 1992 and is now only 15 m below sea level.

In terms of ecology, Surtsey is one of few study areas, worldwide, where long-term data has been maintained on primary succession (Kristín Svavarsdóttir and Walker 2006). Others include volcanic surfaces on Krakatau, Indonesia (since 1908); glacial moraines at Glacier Bay, Alaska, USA (since 1923); and sand dunes in Cooloola, Australia (since 1962) (see Walker and del Moral 2003). On Surtsey, it is expected that stable communities will take several hundred to several thousand years to develop, based on similar histories of nearby islands in the Vestmannaeyjar archipelago.

Sturla Friðriksson and Ian Thornton, two well known island ecologists, on Surtsey in 1990. Ian Thornton (1926 – 2002) was a professor of zoology at La Trobe University, Melbourne, Australia and a leader of ecological research on Krakatau for a number of years. (Photo: Borgþór Magnússon).

The record of ecological research on Surtsey, which spans 40 years of regular measurements, is exceptional for many reasons, among which are the pristine condition maintained on the island, the data obtained by monitoring individual plant species, and the thorough surveys conducted on the island in its entirety (Sturla Friðriksson 2005).

In addition to the research already carried out at Surtsey, there are many potential, non-destructive measurements which would continue to further our understanding of primary succession. These include, to name but a few: studies of nutrient dynamics (particularly of nitrogen and phosphorus); the links between nutrient fluxes and changes in both vascular plant and underground invertebrate populations; carbon accumulation by species and location; the roles of herbivores and mycorrhizae in succession and the ramifications of escaping from mainland herbivores; the microhabitats which plants colonise and how these are partitioned among functional groups; and the role of spatial aggregation of plants during succession (Kristín Svavarsdóttir and Walker 2006).

Dense and diverse vegetation has developed within the seagull colony on the lava plain. (Photo: Erling Ólafsson 2005).

The surf is constantly abrading the lava, creating high sea-cliffs. (Photo: Borgþór Magnússon 2005).

Seagulls have been an important catalyst of ecosystem development on Surtsey through the transport of nutrients from the sea onto the island. (Photo: Borgþór Magnússon 2005).

Running water has eroded the cones and formed small gullies. (Photo: Erling Ólafsson 2004).

Boulders on the shore of the northern spit derived from break-up of lava at the other side of the island (Photo: Borgþór Magnússon 2002).

The tephra cones have been converted into dense palagonite tuff, which is very resistant to further erosion.
(Photo: Erling Ólafsson 2005).

Steaming fissures reflect the existence of a hydrothermal system underneath. (Photo: Árni Bragason 2005).

Surtungur, the main lava crater of the volcano, with the palagonite tuff hills in the background. (Photo: Sigmar Metúsalemsson 2001).

(Photo: Snævarr Guðmundsson 2005).

Driftwood on the northern shore provides a shelter for plants and animals. (Photo: Borgþór Magnússon 2005).

The lowland northern spit seen from the pass between the two tuff cones. (Photo: Erling Ólafsson 2004).

Surtsey has offered a rare opportunity to record the flora and fauna of an entire, intact and undisturbed island. (Photo: Erling Ólafsson 2005).

4 State of conservation and factors affecting the property

4.a Present state of conservation

The conservation status of Surtsey island is excellent and the marks of humans minimal. The infrastructure is limited to one field hut, a helicopter pad and an abandoned lighthouse, which will be removed in the summer of 2007.

Surtsey itself, as well as the island's flora and fauna are still fast developing, as ever-increasing numbers of species colonise the island and existing species expand their ranges. As tourism and the exploitation or disturbance of wildlife and vegetation is strictly prohibited, trampling, pillaging or disruption are not conservation issues. No population trends have been observed on the island that can be attributed to local anthropogenic factors

The conservation status of the marine part of the nominated area is less well known, but is considered good as fisheries within the nominated area are of a small scale (see below).

4.b Factors affecting the property

The emerging terrestrial and marine ecosystems of Surtsey are vulnerable to disturbance, natural as well as anthropogenic. The main natural disturbances are the ongoing marine erosion of the coastline and wind erosion of the land surface, both of which should be considered part of the island's past and future natural history. Anthropogenic disturbance is regarded as minimal.

Sandstorm at Austurbunki in 1985. Such sandstorms were common before the tephra cones converted into palagonite tuff. (Photo: Sveinn P. Jakobsson).

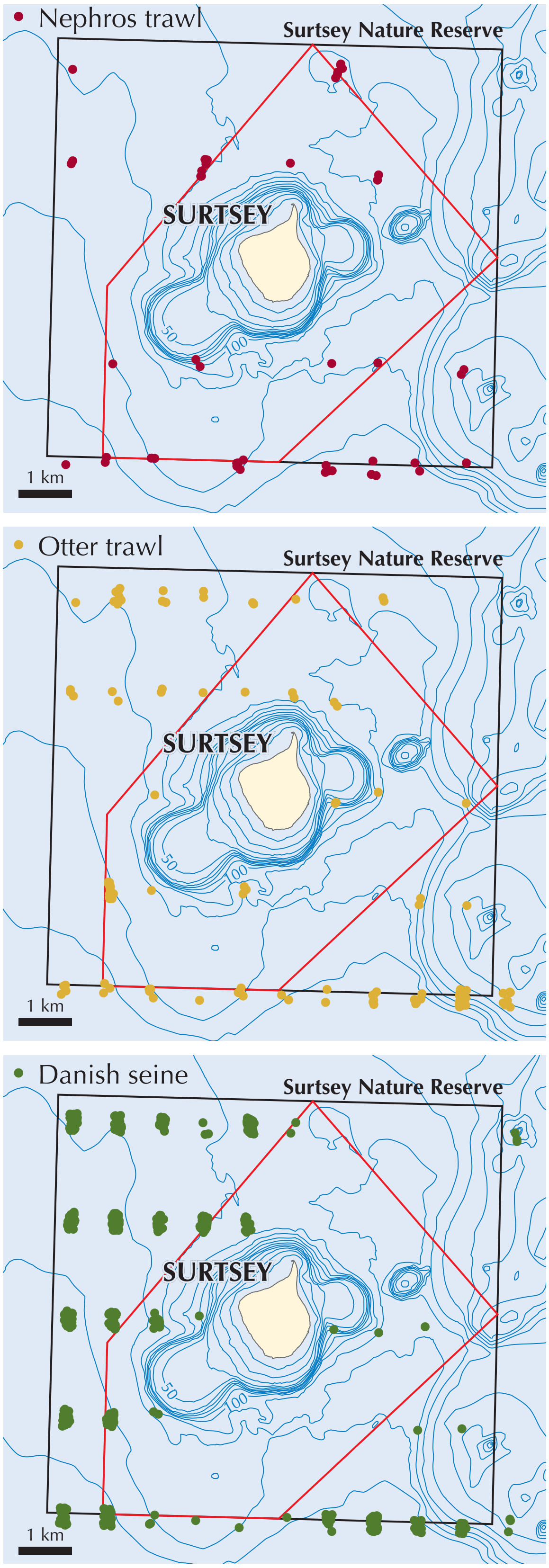


Fig. 4.1. Fishing activities using towed bottom gear in the waters off Surtsey during the period 1987 to 2005. The points refer to the tow starting positions. (Source: Marine Research Institute).

(i) Development pressures

Surtsey has never been inhabited. Construction work is prohibited unless exempted by the Environment and Food Agency. The current declaration of a nature reserve on Surtsey (Chapter 7b) also prohibits mining within the ocean section of the nominated area and restricts fishing with towed bottom gear.

Historically, i.e. between 1965 and 2006, there has been some fishing inside the nominated area. Most of this activity has been concentrated to the west of Surtsey (Fig 4.1). In the period from 1987 to 2005, 25 species were registered in catches in the nominated area of Surtsey nature reserve (Fig 4.2; Appendix 9c). The area's total yearly catches of demersal species amount to about 45 tonnes. The largest catches are of ling *Molva molva*; an average of 12 tonnes per year. Other important species include the cod *Gadus morhua*, haddock *Melanogrammus aeglifinus*, saithe *Pollachius virens* and witch *Glyptocephalus cynoglossus*, all with more than five tonnes average catch per year.

Three types of towed bottom gear have been used: the Nephrops trawl, otter trawl and Danish seine. The Danish seine is most common gear and the average number of sets per year within the nominated area has been about 20 and the yearly catch some 17 tonnes, mainly witch, dab *Limanda limanda* and plaice *Pleuronectes*

Long-line fishing boat south east of Surtsey. Tusk, ling and cod are the primary species taken by long-line in the area. (Photo: Karl Gunnarsson 1996).

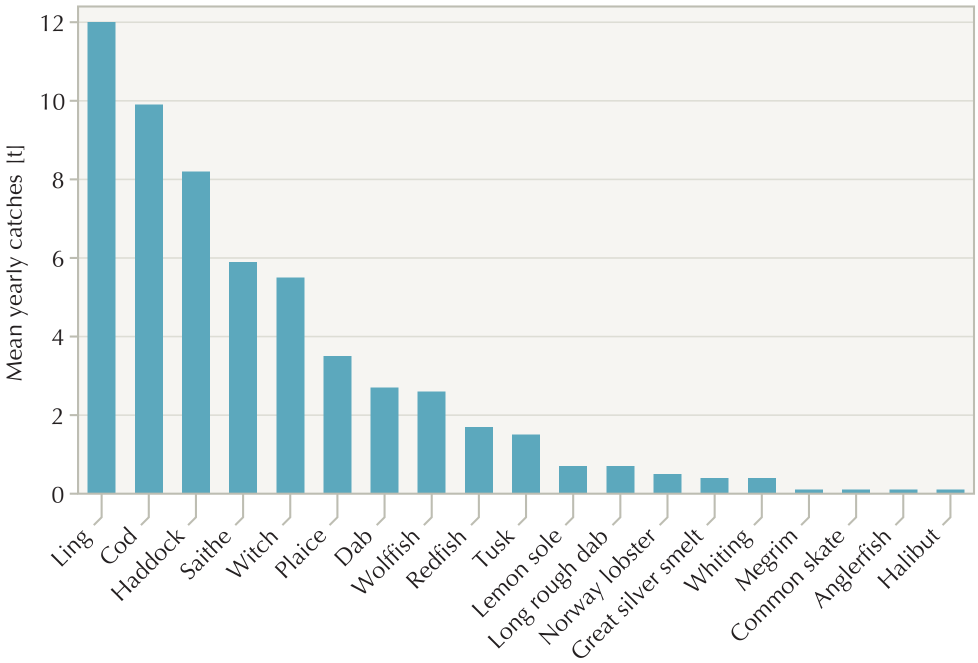


Fig. 4.2. Mean yearly catches of fish and Norway lobster in the Surtsey nature reserve. The figures are averages for the period 1987 to 2005 (Source: Marine Research Institute).

platessa. On average, otter trawl boats have caught some 14 tonnes annually within the nominated area, mainly haddock but also saithe and cod. Boats with the Nephhrops trawl have taken some 0.8 tonnes, of which 0.5 tonnes is Norway lobster *Nephros norvegicus* (Fig 4.2). Fishing with towed bottom gear will be allowed in parts of the buffer zone of the nominated area.

On average, gill nets bring in about 8 tonnes per year within the nominated area, primarily the ling and cod. Other gear types used are the longline and handline. Fishing with gill nets, lines and traps will be allowed within the proposed World Heritage Site.

Currently there are three visible man-made facilities on the island. In 1967, the Surtsey Research Society erected the research field hut "Pálsbær" close to the shore on the northern part of Surtsey. That site was gradually destroyed by ocean erosion. A new hut was erected on the eastern part of the island in 1985 and has been maintained by the Society ever since. Also, a helicopter pad was built close to the hut in 1993. In the late 1980s the Icelandic Maritime Administration decided to erect a lighthouse on top of the eastern tuff crater Austurbunki. Although the lighthouse became inoperative after a few years, the concrete foundation is still in place. Responding to a request by the Icelandic World Heritage Committee, the Ministry of Transport and Communications has agreed to decommission and remove the remnants of the lighthouse and its foundation from Surtsey. The Icelandic Maritime Administration will oversee this removal, which will occur no later than spring or summer of 2007.

Apart from normal maintenance of the field hut Pálsbær and its eventual replacement, there are no plans for additional infrastructures on Surtsey.

(ii) Environmental pressures

Viewed in a broader context, there are no discernible environmental pressures on Surtsey apart from those operating on a larger regional or global scale, such as climate change and atmospheric pollution.

No heavy industry or other activities that handle or produce environmentally hazardous materials are located within a 50-km radius from Surtsey. The dumping of waste at sea, including damaged nets, fishing gear, containers or household garbage, is an issue of concern, as significant quantities of litter wash up on Surtsey's shores every year. This problem is common along the entire Icelandic coastline. A management plan for Surtsey should address how to remove this litter.

The Pálsbær field hut is the only house on Surtsey. The foundation of an abandoned lighthouse is also visible on the top of the hill in the background. The foundation will be dismantled and removed from the island. (Photo: Árni Bragason 2004).

Significant quantities of litter wash up on Surtsey's shores every year. (Photo: Hervé Jezequel 2005).

Large vessels sail along the southern coast of Iceland south of Surtsey. These pose a potential pollution hazard, both now and in the future. The major shipping lane from Europe runs close to the mainland coast, making landfall off Dyrhólaey headland, then lying between the mainland and the Vestmannaeyjar archipelago towards the Reykjanes peninsula. This is the most common route, at least among those familiar with the conditions near land. Another, less frequented shipping lane lies farther south, with landfall at Vestmannaeyjar. This lane then leads south of Surtsey, at a distance of four to ten nautical miles from the island, before heading for the Reykjanes peninsula (Fig 4.3).

Between 1999 and 2001, the Icelandic Maritime Administration prepared a proposal to delimit a zone that would stretch from Dyrhólaey to the south of Vestmannaeyjar, then from there south and west of Fuglasker to Garðskagi, following the limits of the twelve-mile jurisdiction. This zone was to be defined as an "Area to be Avoided", conforming to the rules of the International Maritime Organisation and having the purpose of providing protection by directing oil tanker traffic beyond the area, away from Iceland's coast and the spawning grounds on Selvogsbanki fishing banks. The proposal encountered protests from stakeholders and was not implemented.

The climate of Iceland is expected to warm by 2 to 3° C during this century and precipitation to increase by 10–20% (ACIA 2004). If this proves to be the case, the climate of Iceland will resemble that of the Faroe Islands and northern Scotland by the end of this century. Warming of this magnitude would undoubtedly facilitate vegetation and soil development on Surtsey.

Fig. 4.3. Main shipping routes off the southern coast of Iceland (Source: Icelandic Maritime Administration).

(iii) Natural disasters and preparing for risk

Surtsey is the product of a spectacular natural event, a submarine eruption that lasted for four years, from 1963 to 1967. The new island belongs to the Vestmannaeyjar archipelago, which constitutes a separate volcanic system at the southern end of the Eastern Volcanic Zone of Iceland (Fig. 2.4). As noted above, this is a young volcanic system with its epicentre around Heimaey. There are indications that the Vestmannaeyjar system is approaching a new volcanic episode with the reported submarine eruption in 1896, followed by the Surtsey eruption and the Eldfell eruption 1973. Therefore, a volcanic eruption within the system within the next few decades can not be excluded.

With 1–2 earthquakes per year on the average in the magnitude range 2.0–3.5 on the Richter scale, Surtsey is seismically active. During the time period 1991–2005, 5–6 earthquakes have been recorded annually. No destructive earthquakes are known to have occurred within the Vestmannaeyjar system in historical time.

Several foreign cruise liners sail by Surtsey every summer, allowing thousands of tourists to observe the island from a distance. (Photo: Sigmar Metúsalemsson 2001).

(iv) Visitor/tourism pressures

No tourists are allowed on Surtsey and human presence and influence has been minimal. Since the early 1980s visits to the island have been confined to 6–10 scientists, nature journalists and photographers for one to two weeks each year. Any garbage is brought back to the mainland at the end of each visit. The Vestmannaeyjar Rescue Team travels to Surtsey approximately once a year to look after the field hut, Pálsbær, and a maintenance crew of craftsmen from the Surtsey Research Society visits the island every third or fourth year to repair the hut as needed.

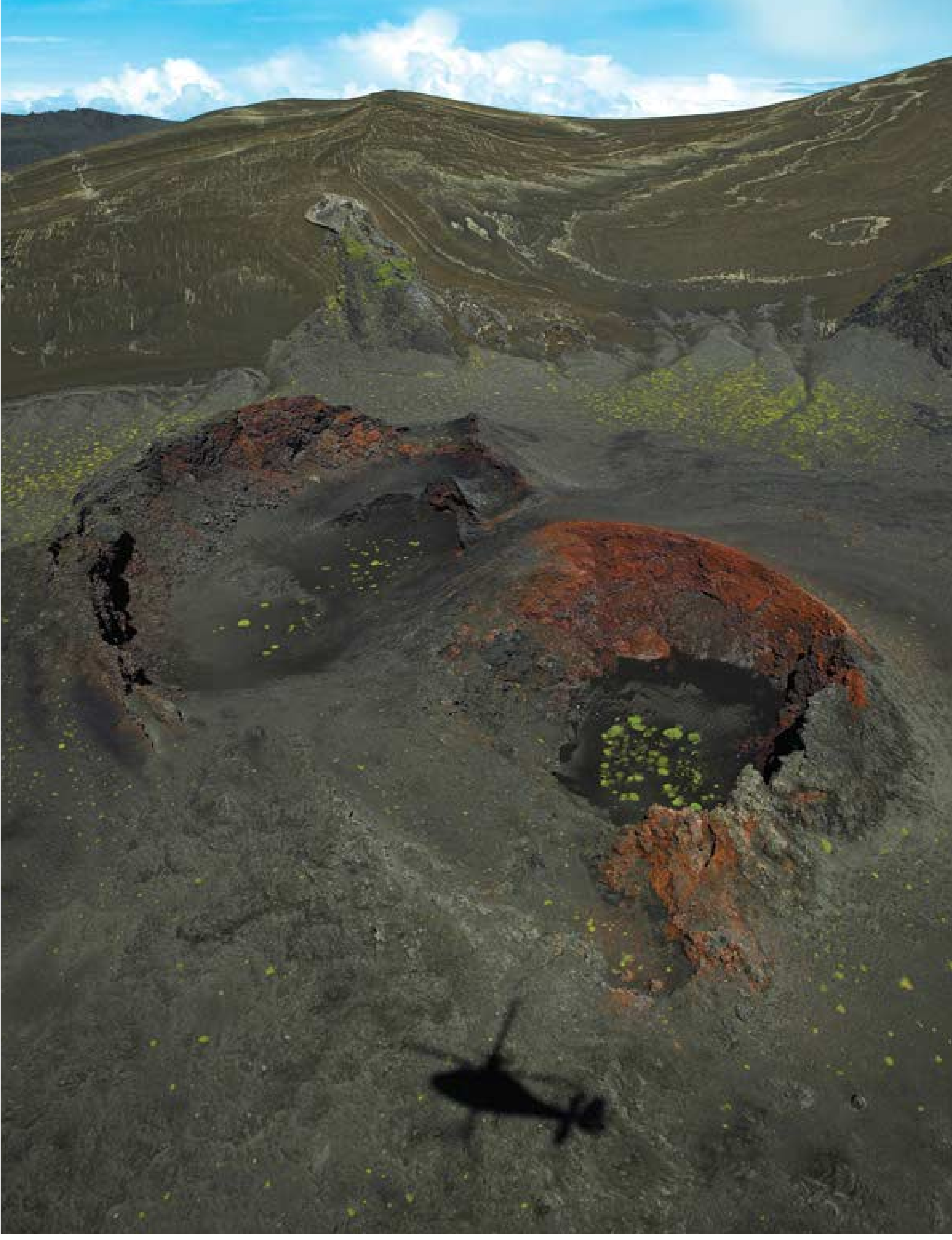
Hence, Surtsey is mainly seen by tourists from the air or sea from sight-seeing flights, tourist boats or cruisers.

Strictly speaking, any visit to Surtsey causes some disruption to the island, including trampling and the possible introduction of species. Researchers and visitors alike can also unwittingly affect how the community of breeding birds develops. Fulmars and gulls are particularly vulnerable in this respect. There have been occasional reports of illegal entry onto the island by people on pleasure boats. However, the current rigorous control of human access, together with the strict protection regime on the island, ensures that human disturbance is minimal.

In spring 2005, a local parliamentary representative formally asked the Minister for the Environment whether there were plans to allow tourist access to Surtsey. On that occasion the Minister declared that there are no plans to change the management regime or access restrictions on Surtsey.

(v) Number of inhabitants within the property and the buffer zone

There are no inhabitants inside the nominated area of Surtsey and never have been. The only inhabited island among the 18 islands in the Vestmannaeyjar archipelago is Heimaey, 18 km NE from Surtsey, with some 4,200 residents.



Aerial view of the crater Surtur.
(Photo: Ragnar Th. Sigurðsson 2005).

5 Protection and management of the property

5.a Ownership

The nominated area is owned by the Icelandic State. The nominated area is protected as a nature reserve according to the Act on nature conservation, No. 44/1999, which applies in Iceland and throughout its territorial waters and exclusive economic zone. The municipality of Vestmannaeyjar serves as the physical planning authority for the area.

5.b Protective designation

In 1965 the Nature Conservation Council (now Environment and Food Agency of Iceland) recommended to the Minister of Education that Surtsey be declared a nature reserve. The intention was to protect and ensure its colonisation and the succession of life under minimal human influence, and to protect its fragile surface and landscape (Appendix 1a). The protection criteria were slightly revised in 1974, in accordance with a new Act on nature conservation that entered into force in 1971 (Appendix 1b). However, the island has *de facto* been managed under IUCN category Ia since 1965, i.e. as a *Strict Nature Reserve: protected area managed mainly for science*.

In January 2006, the boundaries of the nature reserve were expanded to their current outlines (see Chapter 1) and a new and revised declaration of a nature reserve was issued (Chapter 7b). This was done in order to ensure the protection of the entire Surtsey volcanic system, both above and below the sea surface, including the transient islets Jólnir and Syrtlingur as well as the submarine ridge Surtla.

The Surtsey Nature Reserve is protected by the Act on nature conservation, No. 44/1999, as subsequently amended. The objectives of the Act are defined in Article 1 as follows:

"The purpose of this Act is to direct the interaction of man with his environment so that it harms neither the biosphere nor the geosphere, nor pollutes the air, sea or water.... The Act is intended to ensure, to the extent possible, that Icelandic nature can develop according to its own laws and to ensure the conservation of its exceptional or historical aspects... The Act shall facilitate the nation's access to and knowledge of Icelandic nature and cultural heritage and encourage the conservation and utilisation of resources based on sustainable development."

Other articles of the Act on nature conservation which relate to the protection of Surtsey include the following:

- Article 37, which confers special protection *inter alia* to volcanic craters, pseudocraters (rootless vents) and lava fields
- Article 38, which calls for the authorisation of projects by the Environment and Food Agency of Iceland if there is any risk of damage to protected sites of natural interest
- Article 53, which defines nature reserves as "areas which it is important to preserve because of their special landscape or biosphere."

Regulation No. 148/1998 based on Act No. 79/1997 on fishing within the Icelandic Fisheries Jurisdiction further restricts fisheries within the Surtsey nature reserve by banning towed bottom gear in the buffer zone as indicated by a yellow line in Fig. 1.1.

Surtsey with Geirfuglasker in the foreground.
(Photo: Erling Ólafsson 2005).

5.c Means of implementing protective measures

The Act on nature conservation (No. 44/1999, in Article 37) grants special protection to certain landscape and habitat types, including volcanic craters, pseudocraters (rootless vents) and lava fields. No one is allowed to alter, damage or destroy features that fall under Article 37 without prior consent by the Environment and Food Agency of Iceland and the relevant municipality.

The declaration of a nature reserve on Surtsey states that violating the protective regulations will result in a fine or imprisonment of up to two years. This provision is based on Article 76 in the Act on nature conservation (No. 44/1999), which reads as follows: *"Anyone who violates the provisions of this Act or rules adopted by virtue thereof shall be subject to fines or imprisonment of up to two years. Fines shall be paid to the State Treasury. Cases under this Article shall be prosecuted in accordance with provisions for criminal proceedings, cf. the Criminal proceedings act, No. 19/1991."*

A management plan will be finalised by May 2006 and further specify implementation measures for the Surtsey nature reserve.

5.d Existing plans related to the municipality and region in which the proposed property is located

A *Nature Conservation Strategy, 2004–2008*, was confirmed by the Icelandic Parliament in 2004. This Strategy, to be renewed every five years, is meant to ensure the protection of a representative sample of Iceland's biological and geological diversity, as well as sites of outstanding natural beauty or of cultural or historic significance. A large part of the Vestmannaeyjar archipelago is one of the areas scheduled for protection in the Nature Conservation Strategy, 2004–2008. The reasons given include the characteristic and spectacular landscape of the Vestmannaeyjar archipelago and their scientific and educational value in terms of geomorphology; however, their rich birdlife is the foremost reason. For example, Vestmannaeyjar is home to Europe's largest breeding colony of the leach's petrel *Oceanodroma leucorrhoa* and to the only breeding colony of the Manx shearwater *Puffinus puffinus* in Iceland. Over one-third of the Icelandic puffin *Fratercula arctica* population breeds in Vestmannaeyjar, and these islands are of general international importance regarding areas with seabird populations of over one million pairs (Ólafur Einarsson et al. 2002).

The entire country is subject to planning requirements, according to Iceland's Planning and building act, No. 73/1997, No. 135/1997 and No. 58/1999. A municipal plan is a development plan for a specific municipality, detailing the local authority's policy regarding land use, transportation and service systems, environmental matters, and the development of settlement in the municipality over a period of at least 12 years. The *Municipal plan for Vestmannaeyjar archipelago*, 2002–2014, was confirmed by the local government and ratified by the Minister for the Environment on 4 March 2005.

The *Municipal plan for Vestmannaeyjar archipelago* confirms the government's intention to protect the entire archipelago as a managed nature reserve, while allowing sustainable use of its natural resources.

5.e Property management plan or other management system

No overall management plan is yet available for the nominated area; however, a plan is being prepared and will be finalised by 1 May 2006 and submitted to the UNESCO World Heritage Committee. The primary aim of this plan will be to ensure the continued protection and management of the Surtsey Nature Reserve.

The Surtsey Research Society, besides coordinating and enhancing scientific work on Surtsey, has functioned since 1965 as an official guardian of the island. In the 1974 declaration of a nature reserve on Surtsey (Appendix 1b), the Nature Conservation Council (now the Environment and Food Agency of Iceland) bestowed supervision of the island upon the Society.

Supervision includes *inter alia* maintenance of

“A room with a view.” (Photo from within Pálsbær: Borgþór Magnússon 2005).

Scientists boarding a helicopter from the Icelandic Coast Guard after a successful expedition to Surtsey in 2004. (Photo: Erling Ólafsson).

the field hut, keeping track of scientific missions and other visits to the island, informing people about the conservation regime on the island and reviewing applications for permission to go ashore on the island. More or less all scientists and researchers that have formally applied for permission to conduct scientific research on Surtsey have been granted such permission. Natural history journalists and photographers have also, with few exceptions, been granted permission to visit Surtsey, while most other applications have been turned down.

The Society's Rules on Pálsbær remind guests of the hut not being a mere shelter for the shipwrecked, but also a centre for important scientific research. Therefore, it is highly important that every rule be strictly adhered to, such as avoiding bringing any soil traces, organisms or pollutants to the island, or leaving any organic waste on the island.

The current declaration of a nature reserve on Surtsey (2006) states that the Environment and Food Agency of Iceland has overall responsibility for the nature reserve. The Surtsey Research Society coordinates and promotes scientific research on Surtsey. The Icelandic Institute of Natural History is engaged in scientific research and responsible for monitoring activities, carried out in cooperation with the Marine Research Institute and the Surtsey Research Society (Chapter 7b). The roles of these four key players will be further specified in the above mentioned management plan.

5.f Sources and levels of finance

The Surtsey Research Society receives a small yearly allocation (some 7,000 EUR) through the State Treasury budget, which is used to publish the periodical *Surtsey Research*, keep up the Society's homepage (www.surtsey.is) and maintain the field hut Pálsbær. All work conducted by the Society's members is voluntary.

The Icelandic Institute of Natural History and the Marine Research Institute provide significant in-kind support by financing scientific research and the monitoring of Surtsey. Previously this also applied to the Agricultural Research Institute, which participated actively in field work on Surtsey until the 1990s. The Icelandic Coast Guard also provides significant in-kind support by transporting scientists and their crews to the island.

5.g Sources of expertise and training in conservation and management techniques

The Environment and Food Agency of Iceland has staff trained in conservation management, including wardens in the national parks and nature reserves managed by the Agency.

The Icelandic Institute of Natural History and the Marine Research Institute, which are now the two main institutes engaged in research on Surtsey, have experts in the fields of geology, geomorphology, volcanology, geography, petrography, oceanography, zoology, botany and ecology. These experts are active in basic nature research, environmental monitoring and resource management at national, Nordic, European and international levels and have the necessary expertise to underpin the long-term protection and management of the area.

On a local level, the Vestmannaeyjar Research Centre and the South Iceland Nature Research Centre in Vestmannaeyjar town employ several geologists and biologists who are mainly engaged in local research and monitoring.

5.h Visitor facilities and statistics

The town of Vestmannaeyjar can be reached by air or by ferry from the mainland. Accommodation is available at hotels, hostels and campsites. There are several visitor attractions on the island, including a folk museum, art museum, photography museum and aquarium. The latest star attraction is the *Pompei of the North* project – excavation of houses that were buried under tephra during the volcanic eruption on Heimaey in 1973, which was the first eruption in an densely populated area in Iceland's history and a major economic disaster. The objective of this project is to give visitors the opportunity to see what actually happened.

Surtsey is protected as a strict nature reserve and closed to the general public. Although tourists are not allowed to visit Surtsey, they can view it from the air and from the sea. Aerial sightseeing tours are available from Reykjavik and the town of Vestmannaeyjar and provide an excellent view of the island. Boat trips are also available from the Vestmannaeyjar harbour. The duration of a round trip by boat is about 4–5 hours.

Scientists have accessed the island by boat and rubber rafts, small planes and helicopters. A small airstrip was in operation until 1976, but is no longer usable or visible. Since then, the only air transportation has been by helicopter. The field hut Pálsbær has all the necessary accommodation facilities and can easily take 8–10 people.

5.i Policies and programmes related to the presentation and promotion of the property

The Surtsey Research Society has been instrumental in providing information and promoting Surtsey from the very beginning.

The Surtsey Research Society maintains a website (www.surtsey.is) with information on the Society, the origin and development of Surtsey and its ecosystem, scientific work on Surtsey, and the protection of the island as a nature reserve. The Society publishes *Surtsey Research* (formerly the *Surtsey Research Progress Report*), which is now available on the web site. The series includes eleven issues, with the first one published in 1965 and the twelfth issue being prepared for publication. The reports to date contain 201 papers by scientists who have worked or are working on Surtsey. These reports are the most reliable and comprehensive information available on the island's development and on scientific findings concerning the island. The full Surtseyan bibliography is extensive: over 900 papers and books have been published on the island's development. The full bibliography can be accessed at the Surtsey website.

Other sources of information about Surtsey and its environs include the following: the Environment and Food Agency of Iceland (www.ust.is), Icelandic Institute of Natural History (www.ni.is), Vestmannaeyjar Research Centre (www.setur.is), South Iceland Nature Research Centre (www.nattsud.is), Vestmannaeyjar municipality (www.vestmannaeyjar.is) and Heimaslóð – Vestmannaeyjar (www.heimaslod.is).

Scientists are among the few allowed to visit Surtsey; here an entomologist at work in the seemingly lifeless desert. (Photo: Erling Ólafsson 2005).

The Surtsey Research Society has coordinated several national and international conferences and meetings focusing on various aspects of Surtsey. The *Surtsey Biology Conference* was held in Reykjavik in April 1965 with 38 participants: 22 from Iceland and 16 from abroad. A Biological Outline for research on and around Surtsey was presented, "evaluated, scrutinised and accepted", as stated in the minutes from the conference. A second conference, the *Surtsey Research Conference*, was held in Reykjavik in June 1967, with a total of 76 participants: 36 from Iceland and 40 from abroad. The thirty- and forty-year anniversaries of the Surtsey eruption have been commemorated by open seminars in Reykjavik. In the autumn of 2005, a workshop, *Surtsey and its management*, was held in the town of Vestmannaeyjar. At this workshop, scientists outlined the geological and ecological development of the island and participants discussed its significance and future.

5.j Staffing levels

All areas in Iceland which are protected according to the Act on nature conservation are overseen by the Nature Conservation and Outdoor Recreation Division at the Environment and Food Agency of Iceland. The Division employs staff trained in the conservation and management of protected areas. During the summer months, several wardens are employed at protected areas. Every warden must attend a special training course in environmental law, conservation and outdoor recreation, and the duties of the warden are to aid and guide visitors and to interpret the locality's natural and cultural phenomena.

The small crater Bjallan.
(Photo: Hervé Jezequel 2005).

6 Monitoring

6.a Key indicators for measuring the state of conservation

As explained in Chapter 4, there are few discernible environmental pressures at work on Surtsey, and its conservation status is considered excellent. Under the current regime of strict protection, the Surtsey island essentially protects itself. Among the several natural parameters being regularly monitored (see below), various long-term aspects of vegetation will in particular provide important baselines and indicators concerning the response of a young island system to disturbances such as climatic change. On the other hand, these are not measures of the state of conservation at the local level.

There are no plans to use the island for tourism in the near future. As noted above, the abandoned lighthouse building will be removed in the summer of 2007, latest.

Outside pressures include litter, which the sea washes up on the beach every year and may be potentially hazardous for birds. Shipping accidents and oil spills that would affect Surtsey are considered unlikely. However, an emergency procedure and response plan for potential oil spills should be developed as part of a management plan for the nominated area.

Key natural features which have so far been regularly monitored on Surtsey or have relevance to it include:

- The influx and colonisation of new species of vascular plants, mosses, lichens, insects and birds – monitored annually
- Vegetation development within permanent plots – monitored bi-annually
- Ecosystem parameters (plant biomass, soil respiration, soil chemistry, etc.) within permanent plots – monitored every few years
- Thorough bird surveys – conducted every ten years
- Size and outline of the island, as shown by aerial photographs – every second year
- Development and extent of the palagonite tuff – monitored every second year
- Development of the hydrothermal area through temperature measurements – every second year
- Survey of coastal and submarine biota – every ten years.
- Since 1988, offshore wave measurements at a depth of 130 m – regularly
- Record of climate (wind speed, temperature, precipitation) at Stórhöfði, some 19 km northeast of Surtsey – continuously.

The management plan to be developed by May 2006, will further address the issue of indicators to measure the natural state of the Surtsey Nature Reserve and its conservation status.

6.b Administrative arrangements for monitoring property

Although there is no official monitoring programme in effect for Surtsey, it is one of the best- studied and monitored volcanic islands on Earth. This is thanks not least to the generous and patient efforts of the Surtsey Research Society, which has facilitated and encouraged research on the island for 40 years.

The Society itself, however, does not carry out research or process research data. Aside from numerous individual scientists, the lion's share of field work on the island has historically been borne by the Icelandic Institute of Natural History, the Marine Research Institute, the Agricultural Research Institute, the National Energy Authority and the Science Institute of the University of Iceland.

In recent years this has changed somewhat, so that most of the scientific research and monitoring relating to the terrestrial environment, including both geology and biology (see Chapter

A team of ecologists sampling vegetation in one of the permanent study plots on Surtsey. (Photo: Erling Ólafsson 2003).

6a), has been undertaken by the Icelandic Institute of Natural History. Flora and fauna studies (of new colonisers) are performed every year, while other biological and geological investigations are conducted every second year or less frequently (see Chapter 6a).

The Marine Research Institute and the Icelandic Maritime Association are responsible for monitoring the coastal and marine environments.

Until recently, the National Land Survey of Iceland saw to all aerial photography of Surtsey, but this is now carried out by Loftmyndir Ltd.

6.c Results of previous reporting exercises

In September 2005, an open seminar was held in the town of Vestmannaeyjar on the subject *Surtsey and its management*. On this occasion, scientists and representatives of the local community discussed the island's future management, including whether to relax the strict provisions regarding visits to the island and allow controlled tourism. An important conclusion of the seminar was that it would be unwise at present to lift the tourist ban on Surtsey, both because it would jeopardise the scientific value of the island as purely a laboratory of nature and also because transport to and from the island, whether by boat or air, is unsafe. Day tourists might thus risk having to spend the night on the island without proper facilities. The seminar also recommended that a *Surtsey Centre* be established in the town, with the mission of informing people about Surtsey and its wonders, organising boat trips there, etc.

Participants at the workshop, Surtsey and its management, in the town of Vestmannaeyjar, September 2005. (Photo: Ómar Garðarsson 2005).

7 Documentation

7.a Supplementary material

This nomination report is supplemented by the following audiovisual and printed material:

- A videotape with three films by Ósvaldur Knudsen (1965, 1967 and 1973): Birth of an island; Sequel to Surtsey; and Land out of the ocean. Additional filming and editing by Villi Knudsen.
- A Videotape/DVD by Páll Steingrímsson (1993): Surtsey 30-years of age [in German].
- A DVD by Helga Brekkan and Torgny Nordin (2003): The black island.
- A book by Sturla Friðriksson (2005): Surtsey, ecosystems formed. Varði, The Surtsey Research Society, Reykjavík, 112 pages.
- Surtsey Research Progress Reports No. IX (1982), X (1992) and XI (2000). The Surtsey Research Society, Reykjavík.
- A set of slides.

7.b Declaration of Surtsey Nature Reserve, 2006

ADVERTISEMENT

Of a nature reserve on Surtsey island

Art. 1

Declaration of conservation

The Minister for the Environment has, in consultation with the Minister of Fisheries and in accord with the proposal of the Environment and Food Agency and the Icelandic Institute of Natural History, as well as with the consent of the municipality of Vestmannaeyjar [the Westman Islands], decided to renew the declared conservation of Surtsey in such manner that the declaration of conservation shall apply to the entire volcano, whether above the surface of the sea or underwater, including the craters of Jólnir, Syrtlingur and Surtla, together with a specified area of ocean around the island. The protected area is conserved as a nature reserve in accord with Subparagraph 1 of the first paragraph of Art. 53 of the Act on nature conservation, No. 44/1999.

Art. 2

Objective of conservation

The objective of declaring Surtsey a protected area is to ensure that development of the island will be in keeping with the principles of nature itself, as provided in Art. 1 of the Act on nature conservation. The purpose of conservation is to ensure that colonisation by plants and animals, biotic succession and the shaping of geological formations will be as natural as possible, and that human disruption will be minimised.

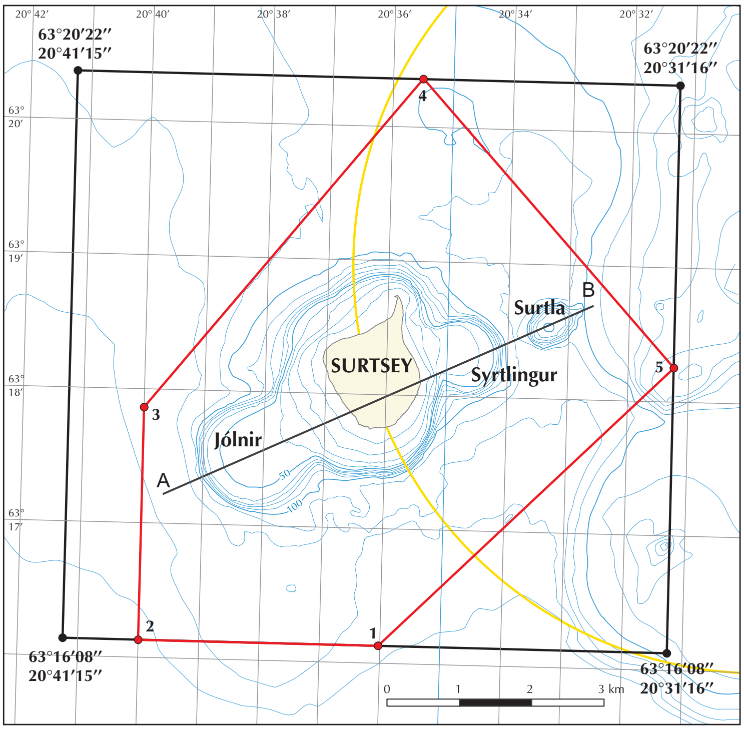
The declaration of conservation is based inter alia upon the great value of the area in scientific and nature conservation terms, both for Iceland and internationally; the area has complete and undisturbed natural features which reflect the developmental processes of nature, and which are highly sensitive to disruption.

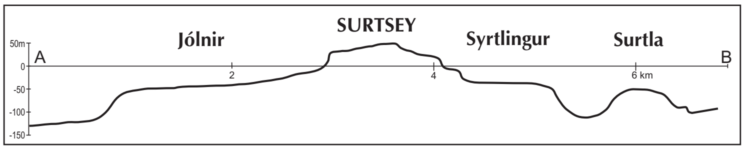
Art. 3

Boundaries of the nature reserve

The nature reserve includes Surtsey above sea level and down to the sea floor, together with an area of ocean around the island which is demarcated by a line drawn between four corner points; see the accompanying table. The coordinates of the points are designated by the ISNET93 system and by longitude and latitude (degrees, minutes and seconds). The boundaries of the area are shown on the accompanying map.

Table	ISNET93		Degrees	
Point	X coordinate	Y coordinate	Longitude	Latitude
1	415350	315875	20º41'15''	63º16'08''
2	423700	315875	20º41'15''	63º20'22''
3	423700	308020	20º31'16''	63º20'22''
4	415350	308020	20º31'16''	63º16'08''





Art. 4

Supervision of the nature reserve, etc.

The Environment and Food Agency conducts the supervision of the nature reserve. A six-member advisory committee shall be appointed to advise the Environment and Food Agency on matters of the nature reserve and shall include one representative of the Surtsey Research Society, of the Icelandic Institute of Natural History, of the Marine Research Institute and of the Environment and Food Agency and two representatives of the municipality of the Westman Islands. The representative of the Environment and Food Agency shall be the committee chairperson. This committee shall be appointed to a term of four years.

The Surtsey Research Society coordinates and seeks to further scientific research on Surtsey and inside the nature reserve boundaries. A special agreement shall be concluded in this regard, to be approved by the Minister for the Environment.

The Icelandic Institute of Natural History conducts research and the regular monitoring of natural conditions in the nature reserve, in cooperation with the Marine Research Institute and Surtsey Research Society.

Art. 5

Access to the nature reserve

It is prohibited to go ashore on Surtsey or to dive by the island except for research purposes and related activities and with the written permission of the Environment and Food Agency.

Vessels are permitted to travel within the reserve around Surtsey.

Art. 6

Conservation of vegetation, animal life and geological formations

It is prohibited to disturb vegetation, animal life or geological formations or other natural features within the reserve.

It is prohibited to transport to the island live animals, plants, seeds or plant parts, or other organisms. Transporting minerals and soil to the island is also prohibited.

Art. 7

Land use and construction

Construction, disturbing the earth, extracting materials and otherwise altering the land or the sea floor within the nature reserve are prohibited, except by permission of the Environment and Food Agency and the Westman Islands municipal council, upon their receiving the opinion of the Surtsey Research Society. It is permissible to maintain such structures as the Surtsey Research Society's hut (Pálsbær) and the helicopter landing facilities on the island, as hitherto and as is described in the conservation plan.

It is prohibited to bury waste or leave it on the island or within the boundaries of the nature reserve.

Art. 8
Fishing and use of firearms

Fishing with fishing gear which is dragged along the sea floor, for instance bottom trawls, Danish seines or dredges, is prohibited in the nature reserve within the area bounded by the following points: 1) 20°36'04'' W and 63°16'08'' N 2) 20°40'00'' W and 63°16'08'' N 3) 20°40'00'' W and 63°17'52'' N 4) 20°35'31'' W and 63°20'22'' N 5) 20°31'16'' W and 63°18'15'' N.

The use of firearms is prohibited within the nature reserve, both on land and at sea.

Art. 9
Exemptions

Upon receiving the opinion of the Environment and Food Agency and the municipality of the Westman Islands, the Minister for the Environment may authorise departures from these rules in particular circumstances, and may provide in more detail for the conservation of the area.

Art. 10
Penalties

Violation of the declared protection entails fines or imprisonment for up to two years.

Art. 11
Entry into force

This declaration of protection shall take effect immediately. At the same time, the advertised Declaration No. 122/1974, of Surtsey as a reserve, expires.

Ministry for the Environment, 27 January 2006

Sigríður Anna Þórðardóttir

[Translation: Lingua / Norðan Jökuls ehf.]

7.c Form and date of recent records

The Surtsey island and volcano has attracted the interest of a large number of scientists. Thus detailed information exists on its natural history in numerous scientific publications, many of which are cited in this nomination report or presented with it as a supplementary material (a full bibliography is also provided at: www.surtsey.is). Sturla Friðriksson's recent book from 2005 *Surtsey, ecosystems formed* provides a general overview of the island's nature.
A geological map, prepared by Sveinn P. Jakobsson in January 2006 (attached), provides the most recent reference to the geology of Surtsey.

7.d Agencies holding important records

Icelandic Institute of Natural History
Hlemmur 3–5
IS-105 Reykjavík

Surtsey Research Society
Hlemmur 3–5
IS-105 Reykjavík

Marine Research Institute
Skúlagata 4
IS-121 Reykjavík

University of Iceland
Suðurgata 1
IS-101 Reykjavík

National Land Survey of Iceland
Stillholti 16–18
IS-300 Akranes

Loftmyndir
Laugavegi 13
IS-101 Reykjavík

Icelandic Maritime Administration
Vesturvör 2
IS-200 Kópavogur

The Icelandic Meteorological Office
Bústaðavegi 9
IS-150 Reykjavík

National and University Library of Iceland
Arngrímsgötu 3
IS-107 Reykjavík

Environment and Food Agency of Iceland
Suðurlandsbraut 24
IS-108 Reykjavík

Agricultural University of Iceland
Keldnaholt
IS-112 Reykjavík

Ministry for the Environment
Skuggasund 1
IS-150 Reykjavík

Ministry of Education, Science and Culture
Sölvhólsgötu 4
IS-150 Reykjavík

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A full bibliography of scientific publications relevant to Surtsey (1963–2006) is provided on a separate CD, attached to this nomination report, and can be found as well at: www.surtsey.is

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The western sea-cliffs of Surtsey.
(Photo: Ragnar Th. Sigurðsson 2005).

9 Signature on behalf of the State Party

The Icelandic Government decided in December 2005 to nominate Surtsey for inclusion in the World Heritage List as a natural heritage site.

The nomination is based on extensive scientific research and close observation of the creation and natural history of Surtsey from 1963 to the present time. It is supported by local people, scientists and relevant authorties.

Signed on behalf of the State Party

____

Place and date

______________________________	______________________________
Þorgerður Katrín Gunnarsdóttir	Sigríður Anna Þórðardóttir
Minister of Education, Science and Culture	Minister for the Environment

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From the very beginning man´s influence on Surtsey has been minimal. (Photo: Hervé Jezequel 2005).

Appendices

Appendix 1a. Declaration of Surtsey as a nature reserve

The protection of Surtsey as a nature reserve entered into force through an announcement in the *Official Gazette* on 19 May 1965; below is the code of conduct for the reserve.

The Nature Conservation Council of Iceland

Makes known:
According to the authority provided in Sub-article C of Article One, and the third paragraph of Art. 12 of Act No. 48/1956, on nature conservation, the Nature Conservation Council has determined to declare Surtsey a reserve.

Declaring Surtsey a reserve is done above all for the purpose of ensuring that the colonisation and succession of life on the island in coming years will be as natural as possible and will undergo minimal disturbances caused by man, as this is extremely important from a scientific standpoint. Therefore, it is hereby forbidden to go ashore at Surtsey except with a permit from the Surtsey Research Committee, which, since this committee supervises all scientific investigations at Surtsey, the Nature Conservation Council has decided to entrust with supervision of the island.

It is prohibited to disrupt anything on the island or to transport animals, plants, seeds, or plant parts there, and it is likewise prohibited to leave behind waste of any kind.

Those who might be authorised to go ashore on the island are obliged to adhere in every respect to rules established by the Nature Conservation Council, in consultation with the Surtsey Research Committee, on treatment of the island.

Those violating provisions of this decision will be held responsible in accordance with Art. 33 of Act No. 48/1956 on nature conservation.

Appendix 1 b. Declaration on the nature reserve at Surtsey

The protection of Surtsey was revised through a new Act on nature conservation (No. 47/1971), which entered into force in 1971 (and has since been superseded by Act No. 55/1999). Also, the Ministry of Education, Science and Culture announced this revised protection in the *Official Gazette* (*Law and Ministerial Gazette* B, No. 122/1974), as appearing below.

Declaration on the reserve at Surtsey

In accordance with the authorisation in Art. 24 of Act No. 47/1971, on nature conservation, [the Environment and Food Agency] has decided for its part to declare Surtsey a reserve.
The following rules shall apply to this reserve:

2. It is forbidden to go ashore on the island except by permission of the Surtsey Research Society, which supervises scientific research there and which [the Environment and Food Agency] has entrusted with supervising the island.
3. It is prohibited to disrupt anything on the island. Permission from [the Environment and Food Agency] is required to build any lasting man-made structure.
4. It is prohibited to bring any live animals, plants, seeds or plant parts to the island.
5. It is prohibited to leave behind any kind of waste on the island or in its proximity.
6. Shooting is prohibited within 2 km of the island.

Sanctions for violating these rules shall be in accordance with provisions of the Act on nature conservation.

Previous provisions on protecting the island are hereby revoked.

The Ministry has approved the declaration of the reserve, and this declaration is hereby published with reference to Art. 32 and 33 of Act No. 47/1971, on nature conservation, and reserve status shall take effect upon publication of this advertisement in the *Law and Ministerial Gazette*.

In the Ministry of Education, Science and Culture, 3 April 1974

Magnús T. Ólafsson

Knútur Hallsson

Appendix 2. Vascular plants on Surtsey

Species found from 1965 to 2005

		Species status in 2005		
		Alive	Viable population	In permanent plots
Pterydophytes				
Cystopteris fragilis (L.) Bernh.	Brittle bladder-fern	X	X	
Equisetum arvense L.	Field horsetail	X		
Polypodium vulgare L.	Common polypody	X		
Monocots				
Grasses				
Agrostis capillaris L.	Common bent	X	X	X
Agrostis stolonifera L.	Creeping bent	X	X	X
Agrostis vinealis Schreber	Velvet bent			
Alopecurus geniculatus L.	Marsh foxtail	X		
Anthoxanthum odoratum L.	Sweet vernal-grass	X		
Deschampsia beringensis Hult.	Bering's tufted hairgrass	X		
Festuca rubra L. ssp. richardsonii (Hook.) Hultén	Arctic fescue	X	X	X
Leymus arenarius (L.) Hochst.	Lyme-grass	X	X	X
Phleum pratense L.	Timothy	X		
Poa annua L.	Annual meadow-grass	X	X	X
Poa glauca Vahl	Glaucous meadow-grass	X		
Poa pratensis L.	Smooth meadow-grass	X	X	X
Puccinellia capillaris (Lilj.) Jansen	Reflexed saltmarsh-grass	X	X	X
Puccinellia coarctata Fern & Weath	Common saltmarsh-grass			
Sedges and rushes				
Carex maritima Gunnerus	Curved sedge	X	X	X
Eleocharis quinqueflora (F. X. Hartmann) O. Schwarz	Few-flowered spike-rush	X		
Juncus alpinoarticulatus Chaix	Alpine rush	X		X
Juncus arcticus Willd. ssp. *intermedius* Hyl.	Iceland rush	X		
Luzula multiflora (Retz.) Lej.	Heath wood-rush	X		
Luzula spicata (L.) DC.	Spiked wood-rush			
Orchids				
Platanthera hyperborea (L.) Lindley	Northern green orchid			

		Species status in 2005		
		Alive	Viable population	In permanent plots
Dicots				
Forbs				
Alchemilla filicaulis Buser	Common lady's-mantle			
Angelica archangelica L.	Garden angelica	X		
Arabidopsis petraea (L.)	Northern rock-cress	X	X	X
Argentina anserina (L.) Rydb.	Silverweed	X	X	
Armeria maritima (Miller) Willd.	Thrift	X	X	X
Atriplex glabriuscula Edmonston	Orache	X		
Cakile arctica Pobed	Sea rocket	X	X	
Capsella bursa-pastoris (L.) Medikus	Shepherd's purse			
Cerastium fontanum Baumg.	Common mouse-ear	X	X	X
Cochlearia officinalis L.	Common scurvygrass	X	X	X
Epilobium palustre L.	Marsh willowherb			
Euphrasia wettsteinii Gussarova	Cold eyebright	X	X	X
Galium normanii O. C. Dahl	Slender bedstraw			
Galium verum L.	Lady's bedstraw	X		
Honckenya peploides (L.) Ehrh.	Sea sandwort	X	X	X
Leontodon autumnalis L.	Autumn hawkbit	X	X	
Mertensia maritima (L.) S. F. Gray	Oysterplant	X	X	X
Montia fontana L.	Blinks	X		X
Myosotis arvensis (L.) Hill	Field forget-me-not	X		
Oxyria digyna (L.) Hill	Mountain sorrel	X		
Plantago lanceolata L.	Ribwort plantain	X		
Plantago maritima L.	Sea plantain	X		
Polygonum aviculare L.	Knotgrass			
Ranunculus acris L.	Meadow buttercup	X	X	X
Rumex acetocella L.	Sheep's sorrel	X	X	X
Rumex acetosa L.	Common sorrel	X	X	X
Rumex longifolius DC. (Danser) Rech. f.	Northern dock	X	X	
Sagina procumbens L.	Procumbent pearlwort	X	X	X
Silene uniflora Roth	Sea campion	X	X	X
Stellaria media (L.) Vill.	Common chickweed	X	X	X
Taraxacum sp.	Dandelion	X	X	
Tripleurospermum maritimum (L.) W. D. J. Koch	Sea mayweed	X	X	X
Dwarf shrubs				
Empetrum nigrum L.	Crowberry	X	X	X
Salix herbaceae L.	Dwarf willow	X	X	
Salix lanata L.	Woolly willow	X		
Salix phylicifolia L.	Tea-leaved willow	X		
Total: 60 species		51	30	25

English names from:
Hörður Kristinsson. A Guide to the Flowering Plants and Ferns of Iceland. Mál og menning, Reykjavík 1998.

Appendix 3. Bryophyte species recorded on Surtsey

	In permanent plots
Amblystegium serpens (Hedw.) Schimp.	
Amphidium lapponicum (Hedw.) Schimp.	
Anomobryum julaceum (P. Gaertn. et al.) Schimp.	
Aongstroemia longipes (Sommerf.) Bruch et Schimp.	
Atrichum undulatum (Hedw.) P. Beauv.	
Aulacomnium palustre (Hedw.) Schwägr.	
Barbula unguiculata Hedw.	
Bartramia ithyphylla Brid.	
Brachythecium albicans (Hedw.) Schimp.	X
Brachythecium rivulare Schimp.	
Brachythecium rutabulum (Hedw.) Schimp.	
Brachythecium salebrosum (F. Weber et D. Mohr) Schimp.	X
Brachythecium velutinum (Hedw.) Schimp.	
Bryoerythrophyllum recurvirostrum (Hedw.) P. C. Chen	
Bryum argenteum Hedw.	X
Bryum dichotomum Hedw.	X
Bryum imbricatum (Schwägr.) Bruch et Schimp.	
Bryum klinggraeffii Schimp.	
Bryum pallens Sw.	
Bryum pallescens Schleich. ex Schwägr.	
Bryum salinum I. Hagen ex Limpr.	
Cephaloziella divaricata (Sm.) Schiffn.	X
Cephaloziella hampeana (Nees) Schiffn.	X
Ceratodon purpureus (Hedw.) Brid.	X
Dichodontium pellucidum (Hedw.) Schimp.	
Dicranella crispa (Hedw.) Schimp.	
Dicranella schreberiana (Hedw.) Dixon	
Dicranella varia (Hedw.) Schimp.	
Dicranoweisia crispula (Hedw.) Milde	
Didymodon fallax (Hedw.) R. H. Zander	
Didymodon icmadophilus (Schimp. ex Müll. Hal.) K. Saito	
Didymodon insulanus (De Not.) M. O. Hill	
Distichium capillaceum (Hedw.) Bruch et Schimp.	
Ditrichum cylindricum (Hedw.) Grout	
Ditrichum heteromallum (Hedw.) E. Britton	
Drepanocladus aduncus (Hedw.) Warnst.	X
Drepanocladus polygamus (Schimp.) Hedenäs	
Encalypta ciliata Hedw.	

	In permanent plots
Fissidens adianthoides Hedw.	
Funaria hygrometrica Hedw.	
Grimmia torquata Hornsch. ex Grev.	
Hypnum lindbergii Mitt.	
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	
Jungermannia pumila With.	
Leptobryum pyriforme (Hedw.) Wilson	
Lophozia excisa (Dicks.) Dumort.	
Marchantia polymorpha L.	
Mnium hornum Hedw.	
Oncophorus virens (Hedw.) Brid.	
Philonotis arnellii Husn.	
Philonotis tomentella Molendo	
Plagiomnium cuspidatum (Hedw.) T. J. Kop.	
Pogonatum urnigerum (Hedw.) P. Beauv.	
Pohlia annotina (Hedw.) Lindb.	
Pohlia filum (Schimp.) Mårtensson	
Pohlia wahlenbergii (F. Weber et D. Mohr) A. L. Andrews	
Polytrichum alpinum Hedw.	
Polytrichum longisetum Sw. ex Brid.	
Polytrichum piliferum Hedw.	
Polytrichum sphaerothecium (Besch.) Müll. Hal.	
Psilopilum laevigatum (Wahlenb.) Lindb.	
Racomitrium ericoides (Brid.) Brid.	X
Racomitrium fasciculare (Hedw.) Brid.	X
Racomitrium lanuginosum (Hedw.) Brid.	X
Reboulia hemisphaerica (L.) Raddi	
Rhytidiadelphus squarrosus (Hedw.) Warnst.	
Sanionia uncinata (Hedw.) Loeske	X
Scapania scandica (Arnell et H. Buch) Macvicar	
Schistidium flexipile (Lindb. ex Broth.) G. Roth	X
Schistidium frigidum H. H. Blom	
Schistidium maritimum (Turner) Bruch et Schimp.	X
Schistidium strictum (Turner) Loeske ex Mårtensson	X
Straminergon stramineum (Brid.) Hedenäs	
Trichostomum brachydontium Bruch	
Ulota phyllantha Brid.	X

Appendix 4. Lichens species recorded in Surtsey

Fruticose lichens:

Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.
Cladonia furcata (Huds.) Schrad.
Cladonia islandica nom. prov.
Cladonia macroceras (Delise) Hav.
Cladonia pocillum (Ach.) Grognot
Cladonia rangiformis Hoffm.
Cladonia symphicarpa (Flörke) Fr.
Cladonia sp.
Stereocaulon alpinum Laurer
Stereocaulon arcticum Lynge
Stereocaulon capitellatum H. Magn.
Stereocaulon condensatum Hoffm. (?)
Stereocaulon depressum (Frey) I. M. Lamb
Stereocaulon glareosum (L. I. Savicz) H. Magn.
Stereocaulon rivulorum H. Magn.
Stereocaulon spathuliferum Vain.
Stereocaulon tomentosum Fr.
Stereocaulon vanoyei Duv.
Stereocaulon vesuvianum Pers.

Foliose lichens:

Collema tenax (Sw.) Ach. em. Degel.
Leptogium lichenoides (L.) Zahlbr.
Leptogium sp.
Peltigera canina (L.) Willd.
Peltigera didactyla (With.) J. R. Laundon
Peltigera neckeri Hepp. ex Müll. Arg.
Peltigera rufescens (Weiss) Humb. (?)
Peltigera venosa (L.) Hoffm.
Xanthoria candelaria (L.) Th. Fr.
Xanthoria parietina (L.) Th. Fr.

Crustose lichens:

Acarospora smaragdula (Wahlenb.) A. Massal.
Acarospora sp.
Arthonia gelidae R.Sant.
Arthonia lapidicola (Taylor) Branth & Rostr.
Caloplaca citrina (Hoffm.) Th. Fr.
Caloplaca verruculifera (Vain.) Zahlbr.
Calvitimela armeniaca (DC.) Hafellner
Candelariella coralliza (Nyl.) H. Magn.
Catillaria chalybeia (Borrer) A. Massal.
Gyalidea fritzei (Stein) Vězda
Hymenelia arctica (Lynge) Lutzoni
Lecania subfuscula (Nyl.) S. Ekman
Lecanora poliophaea (Wahlenb.) Ach.
Lecanora salina H. Magn.
Lecidea lapicida (Ach.) Ach. var. *pantherina* Ach.
Lichenomphalia sp.
Micarea sp.
Pertusaria lactea (L.) Arnold
Pilophorus cereolus (Ach.) Th. Fr. (?)
Pilophorus dovrensis (Nyl.) Timdal, Hertel & Rambold
Placopsis gelida (L.) Linds.
Placopsis lambii Hertel & V. Wirth
Porpidia cinereoatra (Ach.) Hertel & Knoph
Porpidia flavicunda (Ach.) Gowan (?)
Porpidia melinodes (Körb.) Gowan & Ahti
Porpidia soredizodes (Lamy ex Nyl.) J. R. Laundon
Porpidia tuberculosa (Sm.) Hertel & Knoph
Protopannaria pezizoides (Weber) P. M. Jørgensen & S. Ekman
Psilolechia clavulifera (Nyl.) Coppins
Psilolechia leprosa Coppins & Purvis
Pyrenidium hyalosporum Alstrup, D. Hawksw. & R. Sant.
Rhizocarpon expallescens Th. Fr.
Rhizocarpon lavatum (Fr.) Hazsl.
Rinodina gennarii Bagl.
Scoliciosporum umbrinum (Ach.) Arnold
Stereocaulon tornense (H. Magn.) P. James & Purvis (?)
Trapelia coarctata (Sm.) M. Choisy
Trapelia involuta (Taylor) Hertel
Verrucaria aethiobola Wahlenb.
Verrucaria aquatilis Mudd
Verrucaria sp.

Appendix 5. Fungi species recorded on Surtsey

Fungi on Surtsey island, including species that were isolated from the soil and grown in culture media in the research laboratory.

Absidia corymbifera (Cohn) Sacc. & Trotter
Aphanomycopsis bacillariacearum Scherff.
Arrhenia rustica (Fr.) Redhead, Lutzoni, Moncalvo & Vilgalys
Cadophora fastigiata Lagerb. & Melin
Cadophora malorum (Kidd & Beaumont) W. Gams
Ceriosporopsis halima Linder
Cladosporium macrocarpum Preuss
Dinemasporium marinum Sv. Nilsson
Entoloma sericeum (Bull.) Quél.
Epicoccum nigrum Link
Kirschsteiniothelia maritima (Linder) D. Hawksw.
Lamprospora crouanii (Cooke) Seaver
Lecanicillium psalliotae (Treschew) Zare & W. Gams
Lulworthia medusa (Ellis & Everh.) Cribb & J. W. Cribb
Mucor hiemalis Wehmer
Octospora axillaris (Nees) M.M. Moser
Onygena corvina Alb. & Schwein.
Penicillium citrinum Thom
Penicillium palitans Westling
Peziza varia (Hedw.) Fr.
Phoma putaminum Speg.
Trichoderma harzianum Rifai
Trichoderma viride Pers.: Fr.
Ulocladium botrytis Preuss

Appendix 6. Bird species seen on or around Surtsey

Red-throated diver	*Gavia stellata*
Great northern diver	*Gavia immer*
Northern fulmar*	*Fulmarus glacialis*
Manx shearwater	*Puffinus puffinus*
Storm petrel	*Hydrobates pelagicus*
Leach's petrel	*Oceanodroma leucorhoa*
Gannet	*Sula bassana*
Great cormorant	*Phalacrocorax carbo*
European shag	*Phalacrocorax aristotelis*
Squacco heron	*Ardeola ralloides*
Grey heron	*Ardea cinerea*
Whooper swan	*Cygnus cygnus*
Pink-footed goose	*Anser brachyrhynchus*
Greylag goose*	*Anser anser*
Barnacle goose	*Branta leucopsis*
Brent goose	*Branta bernicla*
European widgeon	*Anas penelope*
European teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
Tufted duck	*Aythya fuligula*
Common eider	*Somateria mollissima*
King eider	*Somateria spectabilis*
Harlequin duck	*Histrionicus histrionicus*
Long-tailed duck	*Clangula hyemalis*
Common scoter	*Melanitta nigra*
Red-breasted merganser	*Mergus serrator*
Merlin	*Falco columbarius*
Gyrfalcon	*Falco rusticolus*
Corncrake	*Crex crex*
Eurasian oystercatcher	*Haematopus ostralegus*
Ringed plover	*Charadrius hiaticula*
Golden plover	*Pluvialis apricaria*
Knot	*Calidris canutus*
Sanderling	*Calidris alba*
Purple sandpiper	*Calidris maritima*
Dunlin	*Calidris alpina*
Common snipe	*Gallinago gallinago*
Whimbrel	*Numenius phaeopus*
Redshank	*Tringa totanus*
Turnstone	*Arenaria interpres*
Red-necked phalarope	*Phalaropus lobatus*
Grey phalarope	*Phalaropus fulicarius*
Arctic skua	*Stercorarius parasiticus*
Great skua	*Stercorarius skua*
Little gull	*Larus minutus*
Black-headed gull	*Larus ridibundus*
Common gull	*Larus canus*
Lesser black-backed gull*	*Larus fuscus*
Herring gull*	*Larus argentatus*
Iceland gull	*Larus glaucoides*
Glaucous gull*	*Larus hyperboreus*
Great black-backed gull*	*Larus marinus*
Kittiwake*	*Rissa tridactyla*
Arctic tern*	*Sterna paradisaea*
Common guillemot	*Uria aalge*
Brünnich's guillemot	*Uria lomvia*
Razorbill	*Alca torda*
Black guillemot*	*Cepphus grylle*
Little auk	*Alle alle*
Common puffin*	*Fratercula arctica*
Turtle dove	*Streptopelia turtur*
Long-eared owl	*Asio otus*
Short-eared owl	*Asio flammeus*
Skylark	*Alauda arvensis*
Swallow	*Hirundo rustica*
Meadow pipit*	*Anthus pratensis*
Rock pipit	*Anthus petrosus*
White wagtail*	*Motacilla alba*
European robin	*Erithacus rubecula*
Redstart	*Phoenicurus phoenicurus*
Wheatear	*Oenanthe oenanthe*
Ring ouzel	*Turdus torquatus*
Fieldfare	*Turdus pilaris*
Song thrush	*Turdus philomelos*
European blackbird	*Turdus merula*
European redwing	*Turdus iliacus*
Garden warbler	*Sylvia borin*
Chiffchaff	*Phylloscopus collybita*
Willow warbler	*Phylloscopus trochilus*
Jackdaw	*Corvus monedula*
Raven (*)	*Corvus corax*
Starling	*Sturnus vulgaris*
Chaffinch	*Fringilla coelebs*
Brambling	*Fringilla montifringilla*
Redpoll	*Carduelis flammea*
Crossbill	*Loxia curvirostra*
Lapland bunting	*Calcarius lapponicus*
Snow bunting*	*Plectrophenax nivalis*
Northern oriole	*Icterus galbula*

* = Have bred on Surtsey

(*) = Have built nests but never laid eggs

Appendix 7. Terrestrial invertebrates recorded on Surtsey

ARTHROPODA Joint-legged animals

INSECTA

Collembola Springtails

Hypogastruridae

Ceratophysella denticulata (Bagnall, 1941)
Ceratophysella succinea (Gisin, 1949)
Hypogastrura assimilis (Krausbauer, 1898)
Hypogastrura purpurescens (Lubbock, 1967)

Neanuridae

Anurida granaria (Nicolet, 1847)
Friesea mirabilis (Tullberg, 1871)

Onychiuridae

Mesaphorura krausbaueri Börner, 1901
Mesaphorura macrochaeta Rusek, 1976
Protaphorura armata (Tullberg, 1869)
Thalassaphorura duplopunctata (Strenzke, 1954)

Isotomidae

Archisotoma besselsi (Packard, 1877)
Desoria violacea (Tullberg, 1876)
Folsomia brevicauda Agrell, 1939
Folsomia fimetaria (Linnaeus, 1758)
Folsomia quadrioculata (Tullberg, 1871)
Isotoma anglicana Lubbock, 1862
Isotoma maritima (Tullberg, 1871)
Isotomiella minor (Schaeffer, 1896)
Parisotoma notabilis (Schaeffer, 1896)
Proisotoma minuta (Tullberg, 1871)
Pseudisotoma sensibilis (Tullberg, 1876)
Vertagopus arboreus (Linnaeus, 1758)

Sminthuridae

Sminthuridae indet. sp.

Neelidae

Neelides minutus (Folsom, 1901)

Protura Proturans

Protentomidae

Protentomon thienemanni Strenzke, 1942

Mallophaga Lice

Menoponidae

Eidmanniella pustulosa (Nitzsch, 1866)

Hemiptera True bugs

Saldidae

Salda littoralis (Linnaeus, 1758)

Corixidae

Arctocorisa carinata (Sahlberg, 1819)

Drepanociphidae

Euceraphis punctipennis (Zetterstedt, 1828)

Aphididae

Acyrtociphon auctum (Walker, 1849)
Brachycaudus helichrysi (Kaltenbach, 1843)
Aphididae indet. spp.

Orthezidae

Arctorthezia cataphracta (Olafsen, 1772)

Thysanoptera Thrips

Thripidae

Apterothrips secticornis (Trybom, 1896)
Aptinothrips rufus (Gmelin, 1788)
Taenipthrips atratus (Haliday, 1836)

Neuroptera Lacewings

Hemerobiidae

Kimminsia betulina (Ström, 1788)

Thricoptera Caddis flies

Limnephilidae

Limnephilus affinis Curtis, 1834
Limnephilus elegans Curtis, 1834
Limnephilus fenestratus (Zetterstedt, 1840)
Limnephilus griseus (Linnaeus, 1758)

Lepidoptera Butterflies

Plutellidae

Plutella xylostella (Linnaeus, 1758)
Rhigognostis senilella (Zetterstedt, 1839)

Gelechiidae

Bryotropha similis (Stainton, 1854)

Tortricidae

Eana osseana (Scopoli, 1763)

Pyralidae

Matilella fusca (Haworth, 1811)
Crambus pascuella (Linnaeus, 1758)
Nomophila noctuella (Denis & Schiffermüller, 1775)

Nymphalidae

Vanessa atalanta (Linnaeus, 1758)
Vanessa cardui (Linnaeus, 1758)

Geometridae

Epirrhoe alternata (Müller, 1764)
Xanthorhoe decoloraria (Esper, 1806)
Xanthorhoe designata (Hufnagel, 1767)

Noctuidae

Agrotis ipsilon (Hufnagel, 1766)
Autographa gamma (Linnaeus, 1758)
Cerapteryx graminis (Linnaeus, 1758)
Chortodes stigmatica (Eversmann, 1855)
Diarsia mendica (Fabricius, 1775)
Euxoa ochrogaster (Guenée, 1852)
Noctua pronuba (Linnaeus, 1758)
Peridroma saucia (Hübner, 1808)
Phlogophora meticulosa (Linnaeus, 1758)

Coleoptera Beetles

Carabidae

Amara quenseli (Schönherr, 1806)
Bembidion bipunctatum (Linnaeus, 1761)
Nebria rufescens (Ström, 1768)
Notiophilus biguttatus (Fabricius, 1779)
Patrobus septentrionis (Dejean, 1828)
Trichocellus cognatus (Gyllenhal, 1827)

Dytiscidae

Agabus bipustulatus (Linnaeus, 1767)

Staphylinidae

Amischa analis (Gravenhorst, 1802)
Atheta amicula (Stephens, 1832)
Atheta atramentaria (Gyllenhal, 1810)
Atheta excellens (Kraatz, 1856)
Atheta fungi (Gravenhorst, 1806)
Atheta graminicola (Gravenhorst, 1806)
Atheta vestita (Gravenhorst, 1806)
Omalium excavatum Stephens, 1834
Oxypoda islandica Kraatz, 1857
Parocyusa rubicunda (Erichson, 1837)

Lathridiidae

Lathridius minutus (Linnaeus, 1767)

Coccinellidae
Coccinella undecimpunctata Linnaeus, 1758
Curculionidae
Barynotus squamosus Germar, 1824
Ceutorhynchus insularis Dieckmann, 1971
Otiorhynchus arcticus (Fabricius, 1780)

Hymenoptera Hymenopterans
Ichneumonidae
Aclastus gracilis (Thomson, 1884)
Atractodes ambiguus Ruthe, 1859
Campoletis sp.
Diadegma boreale Horstmann, 1980
Enizemum ornatum (Gravenhorst, 1829)
Nepiera collector (Thunberg, 1822)
Ophion nigricans Ruthe, 1859
Pimpla arctica Zetterstedt, 1838
Pimpla sodalis Ruthe, 1859
Stilpnus tenebricosus (Gravenhorst, 1829)
Sussaba pulchella (Holmgren, 1858)
Braconidae
Alysia manducator (Panzer, 1799)
Chorebus cf. cytherea (Nixon, 1837)
Chorebus sp.
Dacnusa sp.
Meteorus rubens (Nees, 1811)
Aphidiidae
Monoctonus caricis (Haliday, 1833)
Aphidiidae indet. spp.
Cynipidae
Alloxysta sp.
Eucoilidae
Trybliographa sp.
Pteromalidae
Cyrtogaster vulgaris Walker, 1833
Eupteromalus fucicola (Walker, 1835)
Pteromalidae indet. spp.
Diapriidae
Polypeza ciliata (Thomson, 1859)
Scelionidae
Trimorus sp.
Platygastridae
Platygaster splendidulus Ruthe, 1859
Megaspilidae
Dendrocerus bifoveatus (Kieffer, 1907)

Diptera True flies
Tipulidae
Prionocera turcica (Fabricius, 1794)
Tipula marmorata Meigen, 1818
Tipula rufina Meigen, 1818
Limoniidae
Limonia autumnalis (Staeger, 1840)
Erioptera hybrida (Meigen, 1804)
Anisopodidae
Sylvicola fenestralis (Scopoli, 1763)
Trichoceridae
Trichocera maculipennis Meigen, 1818
Bibionidae
Bibio nigriventris Haliday, 1833
Dilophus femoratus Meigen, 1804
Scatopsidae
Scatopse notata (Linnaeus, 1758)
Sciaridae
Bradysia cf. *nitidicollis* (Meigen, 1818)
Lycoriella conspicua (Winnertz, 1867)
Sciaridae indet. spp.

Mycetophilidae
Brevicornu sp.
Exechia frigida (Boheman, 1865)
Exechia nigra (Edwards, 1925)
Exechia micans Lastovka & Matile, 1974
Chironomidae
Chironomus spp.
Cricotopus sp.
Diamesa bertrami Edwards, 1935
Diamesa bohemani Goetghebuer, 1932
Diamesa incallida (Walker, 1856)
Diamesa zernii Edwards, 1933
Eukiefferiella minor (Edwards, 1929)
Halocladius variabilis (Staeger, 1839)
Metriocnemus eurynotus (Holmgren, 1883)
Micropsectra atrofasciata Kieffer, 1911
Micropsectra lindrothi Goetghebuer, 1931
Paracladopelma laminata (Kieffer, 1921)
Procladius islandicus Goetghebuer, 1931
Psectrocladius limbatellus (Holmgren, 1869)
Smitthia sp.
Tanytarsus gracilentus (Holmgren, 1883)
Telmatogeton japonicus Tokunaga, 1933
Oliverida tricornis (Oliver, 1976)
Ceratopogonidae
Ceratopogonidae indet. sp.
Simuliidae
Simulium aureum (Fries, 1824)
Simulium vittatum Zetterstedt, 1838
Empididae
Clinocera stagnalis (Haliday, 1833)
Dolichopodidae
Dolichopus plumipes (Scopoli, 1763)
Hydrophorus viridis (Meigen, 1824)
Syntormon pallipes (Fabricius, 1794)
Lonchopteridae
Lonchoptera furcata (Fallén, 1823)
Syrphidae
Eupeodes corollae (Fabricius, 1794)
Eupeodes lundbecki (Soot-Ryen, 1946)
Eupeodes punctifer (Frey, 1934)
Helophilus pendulus (Linnaeus, 1758)
Melangyna lasiophthalma (Zetterstedt, 1843)
Melanostoma mellinum (Linnaeus, 1758)
Parasyrphus tarsatus (Zetterstedt, 1838)
Platycheirus albimanus (Fabricius, 1781)
Platycheirus clypeatus (Meigen, 1822)
Platycheirus manicatus (Meigen, 1822)
Platycheirus peltatus (Meigen, 1822)
Syrphus torvus Osten-Sacken, 1875
Phoridae
Megaselia pumila (Meigen, 1830)
Megaselia sordida (Zetterstedt, 1838)
Piophilidae
Piophila vulgaris Fallén, 1820
Sciomyzidae
Pherbellia ventralis (Fallén, 1820)
Tetanocera robusta Loew, 1847
Helcomyzidae
Heterocheila buccata (Fallén, 1820)
Sepsidae
Themira dampfi Becker, 1915
Themira pusilla (Zetterstedt, 1847)
Coelopidae
Coelopa frigida (Fabricius, 1805)

Anthomyzidae
Anthomyza socculata (Zetterstedt, 1847)
Carniidae
Meaneura lamellata Collin, 1930
Heleomyzidae
Heleomyza borealis (Bohemann, 1866)
Heleomyza serrata (Linnaeus, 1758)
Neoleria prominens (Becker, 1897)
Tephrochlaena oraria Collin, 1943
Drosophilidae
Drosophila funebris (Fabricius, 1787)
Scaptomyza graminum (Fallén, 1823)
Scaptomyza pallida (Zetterstedt, 1847)
Sphaeroceridae
Copromyza equina Fallén, 1820
Copromyza nigrina (Gimmerthal, 1847)
Crumomyia nigra (Meigen, 1830)
Kimosina empirica (Hutton, 1901)
Leptocera lutosa (Stenhammar, 1855)
Minilimosina fungicola (Haliday, 1836)
Spelobia clunipes (Meigen, 1830)
Spelobia luteilabris (Rondani, 1880)
Spelobia pseudosetaria (Duda, 1918)
Spelobia rufilabris (Stenhammar, 1855)
Thoracochaeta zosterae (Haliday, 1833)
Ephydridae
Discocerina bohemanni (Becker, 1896)
Hydrellia griseola (Fallén, 1823)
Parydra pusilla (Meigen, 1830)
Philygria vittipennis (Zetterstedt, 1838)
Scatella stagnalis (Fallén, 1823)
Scatella tenuicosta Collin, 1930
Scathophagidae
Chaetosa punctipes (Meigen, 1826)
Scathophaga calida Curtis, 1832
Scathophaga furcata (Say, 1823)
Scathophaga litorea Fallén, 1819
Scathophaga stercoraria (Linnaeus, 1758)
Anthomyiidae
Botanophila betarum (Lintner, 1883)
Botanophila fugax (Meigen, 1826)
Botanophila rubrigena (Schnabl, 1815)
Delia angustifrons (Meigen, 1826)
Delia echinata (Séguy, 1923)
Delia fabricii (Holmgren, 1873)
Delia platura (Meigen, 1826)
Delia radicum (Linnaeus, 1758)
Delia setigera (Stein, 1920)
Fucellia fucorum (Fallén, 1819)
Fucellia maritima (Haliday, 1838)
Lasiomma picipes (Meigen, 1826)
Lasiomma seminitidum (Zetterstedt, 1845)
Pegoplata infirma (Meigen, 1826)
Zaphne brunneifrons (Zetterstedt, 1838)
Zaphne divisa (Meigen, 1826)
Zaphne frontata (Zetterstedt, 1838)
Muscidae
Coenosia pumila (Fallén, 1825)
Graphomyia maculata (Scopoli, 1763)
Helina annosa (Zetterstedt, 1838)
Hydrotaea armipes (Fallén, 1825)
Hydrotaea dentipes (Fabricius, 1805)
Limnophora pandellei Séguy, 1923
Limnophora sinuata Collin, 1930
Musca domestica Linnaeus, 1758
Mydaea palpalis Stein, 1916
Myospila meditabunda (Fabricius, 1781)
Spilogona baltica (Ringdahl, 1918)
Spilogona micans (Ringdahl, 1918)
Spilogona pacifica (Meigen, 1826)
Thricops rostratus (Meade, 1882)
Fanniidae
Fannia canicularis (Linnaeus, 1761)
Fannia glaucescens (Zetterstedt, 1845)
Calliphoridae
Calliphora uralensis Villeneuve, 1922
Calliphora vicina Robineau-Desvoidy, 1830
Cynomya mortuorum (Linnaeus, 1761)
Phormia terraenovae Robineau-Desvoidy, 1830
Hippoboscidae
Ornithomyia avicularia (Linnaeus, 1758)
Ornithomyia chloropus Bergroth, 1901

Siphonaptera Fleas
Ceratophyllidae
Dasypsyllus gallinulae (Dale, 1878)

ARACHNIDA Arachnids

Araneae Spiders
Linyphiidae
Agyneta nigripes (Simon, 1884)
Allomengea scopigera (Grube, 1859)
Erigone arctica (White, 1852)
Erigone atra Blackwall, 1833
Erigone tirolensis L. Koch, 1872
Islandiana princeps Brændegaard, 1932
Lepthyphantes complicatus (Emerton, 1882)
Lepthyphantes mengei Kulczynski, 1887
Lepthyphantes zimmermanni Bertkau, 1890
Leptotrix hardyi (Blackwall, 1850)
Savignya frontata (Blackwall, 1833)
Walckenaeria clavicornis (Emerton, 1882)
Walckenaeria nudipalpis (Westring, 1851)

Acari Mites and ticks
Gammasina
Arctoseius cetratus (Sellnick, 1940)
Dendrolaelaps oudemansi Halbert, 1915
Haemogamasus nidi Michael, 1892
Macrocheles matrius Hull, 1925
Rhodacarus roseus Oudemans, 1902
Thinoseius spinosus Willmann, 1930
Eviphis ostrinus (C. L. Koch, 1836)
Zercon triangularis C. L. Koch, 1836
Arctoseius cetratus (Sellnick, 1940)
Arctoseius sp.
Eugamasus kraepelina (nomen dubium)
Halolaelaps porulus (Göts, 1952)
Halolaelaps suecicus (Sellnick, 1957)
Halolaelaps sp.
Parasitus halophilus Sellnick, 1957
Ixodida
Ixodes ricinus (Linnaeus, 1758)
Ceratixodes uriae (White, 1852)
Actinedida
Cocceupodes clavifrons (Canestrini, 1886)
Ereynetes agilis (Berlese, 1923)
Pedeculaster mesembrinae (Canestrini, 1881)
Tarsonemus fusarii Cooreman, 1941
Nanorchestes arboriger (Berlese, 1904)
Rhagidia mordax Oudemans, 1906

Rhagidia sp.
Penthalodes ovalis (Dugès, 1834)
Petrobia apicalis (Banks, 1917)
Bdella sp.
Neomolgus littoralis (Linnaeus)
Anystis sp.
Bakerdalia sp.

Acaridida

Caloglyphus reglei
Myianoetus digiferus
Myianoetus vesparum
Tyrophagus similis
Tyrophagus dimidiatus
Schwiebia cavernicola
Histiostoma feroniarum
Histiostoma (hypopus)

Oribatida

Lauroppia falcata (Paoli, 1908)
Oribotritia faeroensis (Sellnick, 1923)
Hypochthonius rufulus C. L. Koch, 1836
Liochthonius lapponicus (Trägardh, 1910)
Liochthonius muscorum Forsslund, 1964
Liochthonius propinquus Niedbala, 1972
Eniochthonius minutissimus (Berlese, 1903)
Hermannia sp.
Tectocepheus velatus (Michael, 1880)
Suctobelbella subcornigera (Forsslund, 1941)
Suctobelbella sarekensis (Forsslund, 1941)
Suctobelbella acutidens (Forsslund, 1941)
Quadroppia quadricarinata (Michael, 1885)
Quadroppia sp.
Oppiella nova (Oudemans, 1902)
Oppiella splendens (C. L. Koch, 1841)
Medioppia subpectinata (Oudemans, 1900)
Autogneta longilamellata (Michael, 1885)
Ameronothrus lineatus (Thorell, 1871)
Ameronothrus nigrofemoratus (C. L. Koch, 1879)
Zygoribatula exilis (Nicolet, 1855)
Chamobates cuspidatus (Michael, 1884)
Ophidiotrichus connexus (Berlese, 1904)
Achipteria coleoptrata (Linnaeus, 1758)

ANNELIDA Segmented worms

Oligochaeta Earthworms

Lumbricidae

Lumbricus castaneus (Savigny, 1826)

Enchytraeidae

Enchytraeidae indet. spp.

MOLLUSCA Molluscs

Gastropoda Snails and slugs

Agriolimacidae

Deroceras agreste (Linnaeus, 1758)

Vitrinidae

Vitrina pellucida (O. F. Müller, 1774)

NEMATODA Roundworms

Rhabditina

Cephalobidae

Acrobeloides nanus (de Man, 1884)

Monhysterida

Monhysteridae

Monhystera sp.

RODATORIA Rotifers

Eurolataria

Philodinidae

Philodina acuticornis odiosa Milne, 1916

Habrotrochidae

Habrotrocha

Habrotrocha constricta (Dujardin, 1841)
Habrotrocha sp.

Ploima

Euchlandidae

Euchlanis dilatata Ehrenberg, 1832

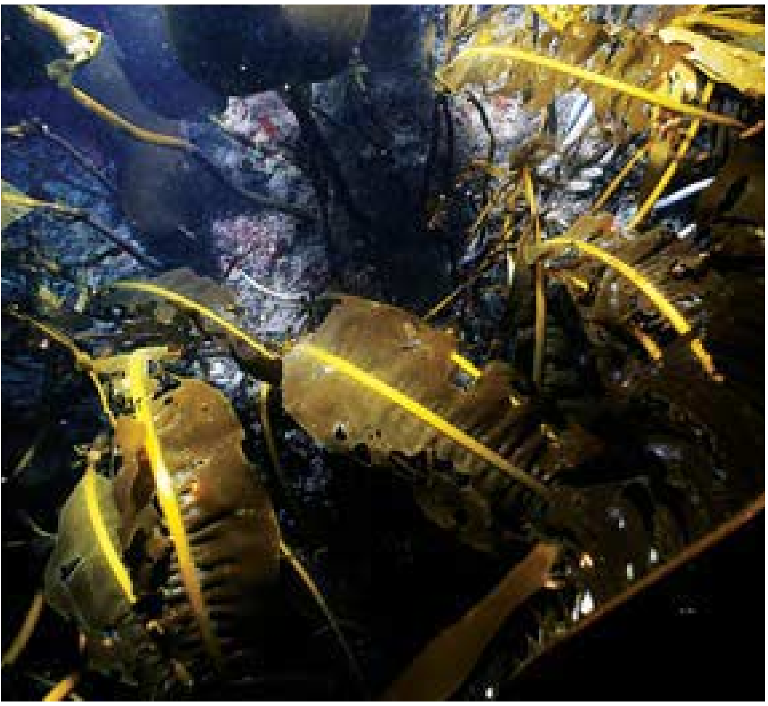
Notommatidae

Cephalodella gibba (Ehrenberg, 1832)
Cephalodella gracilis (Ehrenberg, 1832)

Appendix 8. Seaweed species recorded at Surtsey

Green algae

Acrochaete viridis (Reinke) R. Nielsen
Acrochaete wittrockii (Wille) R. Nielsen
Acrosiphonia arcta (Dillwyn) J. Agardh
Blidingia minima (Nägeli ex Kützing) Kylin
Bryopsis plumosa (Hudson) C. Agardh
Derbesia marina (Lyngbye) Solier
Endodictyon infestans H. Gran
Enteromorpha compressa (Linnaeus) Nees
Enteromorpha flexuosa (Wulfen) J. Agardh
Enteromorpha intestinalis (Linnaeus) Nees
Enteromorpha linza (Linnaeus) J. Agardh
Enteromorpha prolifera (O. F. Müller) J. Agardh
Epicladia flustrae Reinke
Sahlingia subintegra (Rosenvinge) Kornmann
Monostroma grevillei (Thuret) Wittrock
Omphalophyllum ulvaceum Rosenvinge
Pseudentoclonium submarinum Wille
Spongomorpha aeruginosa (Linnaeus) van den Hoek
Ulothrix speciosa (Carmichael ex Harvey in Hooker) Kützing
Ulothrix flacca (Dillwyn) Thuret in Le Jolis
Ulothrix subflaccida Wille
Ulva lactuca Linnaeus
Ulvaria fusca (Postels & Ruprecht) Ruprecht
Urospora bangioides (Harvey) Holmes & Batters
Urospora penicilliformis (Roth) Areschoug
Urospora wormskioldii (Mertens in Hornemann) Rosenvinge



Brown algae

Alaria esculenta (Linnaeus) Greville
Chorda filum (Linnaeus) Stackhouse
Desmarestia aculeata (Linnaeus) Lamouroux
Desmarestia ligulata (Lightfoot) Lamouroux
Desmarestia viridis (O. F. Müller) Lamouroux
Ectocarpus fasciculatus Harvey
Ectocarpus siliculosus (Dillwyn) Lyngbye
Fucus spiralis Linnaeus
Halosiphon tomentosum (Lyngbye) Jaasund
Haplospora globosa Kjellman
Hincksia granulosa (J. E. Smith) P. Silva
Hincksia hincksiae (Harvey) P. Silva
Hincksia ovata (Kjellman) P. Silva
Hincksia recurvata (Kuckuck) unpublished combination
Hincksia secunda (Kützing) P. Silva
Laminaria digitata (Hudson) Lamouroux
Laminaria hyperborea (Gunnerus) Foslie
Leptonematella fasciculata (Reinke) Silva
Petalonia fascia (O. F. Müller) Kuntze
Petalonia zosterifolia (Reinke) Kuntze
Petroderma maculiforme (Wollny) Kuckuck
Phaeostroma pustulosum Kuckuck
Protectocarpus speciosus (Børgesen) Kornmann in Kuckuck
Pylaiella littoralis (Linnaeus) Kjellman
Scytosiphon lomentarius (Lyngbye) Link
Sphacelaria caespitula Lyngbye

Red algae

Achrochaetium secundatum (Lyngbye) Nägeli
Antithamnionella floccosa (O. F. Müller) Whittick
Audouinella membranacea (Magnus) Papenfuss
Audouinella pectinata (Kylin) Papenfuss
Bangia artropurpurea (Roth) C. Agardh
Callophyllis cristata (C. Agardh) Kützing
Delesseria sanguinea (Hudson) Lamouroux
Lomentaria clavellosa (Turner) Gaillon
Lomentaria orcadensis (Harvey) Collins ex W. R. Taylor
Meiodiscus spetzbergensis (Kjellm) G. W. Saunders & McLachlan
Membranoptera alata (Hudson) Stackhouse
Phycodrys rubens (Linnaeus) Batters
Erythrodermis traillii (Holmes ex Batters) Guiry & Garbary
Plocamium cartilagineum (Linnaeus) Dixon
Polysiphonia stricta (Dillwyn) Greville
Porphyra miniata (C. Agardh) C. Agardh
Porphyra purpurea (Roth) C. Agardh
Porphyra umbilicalis (Linnaeus) Kützing
Porphyropsis coccinea (J. Agardh ex Areschoug) Rosenvinge
Rhodochorton purpureum (Lightfoot) Rosenvinge
Rhodophysema elegans (P. Crouan & H. Crouan) Dixon
Scagelothamnion pusillum (Ruprecht) Athanasiadis in Maggs & Hommersand

Appendix 9a. Marine zoobenthos found on hard substrate at 0 to 40 m depth at Surtsey

The following animal species were collected in the littoral and sublittoral zones down to depths of 40 m.

Porifera sponges
Grantia compressa (Fabricius, 1780)
Halichondria panicea (Pallas, 1766)
Sycon ciliatum (Fabricius, 1780)

Scyphozoa stalked jellyfish
Haliclystus octoradiatus (Lamarck, 1816)

Hydrozoa hydroids
Aequorea forskalea (Forsskal, 1775)
Bougainvillia ramosa (Van Beneden, 1844)
Callycella syringa (Linnaeus, 1767)
Campanularia integra Macgillivray, 1842
Clytia hemisphaerica (Linnaeus, 1758)
Clytia sarsi Cornelius, 1982
Corymorpha nutans M. Sars, 1835
Cuspidella humilis (Alder, 1862)
Diphasia rosacea (Linnaeus, 1758)
Dulichia porrecta (Bate, 1857)
Eudendrium capillare Alder, 1856
Eudendrium rameum (Pallas, 1766)
Filellum serpens (Hassall, 1848)
Halecium curvicaule Lorenz, 1886
Halecium halecium (Linnaeus, 1758)
Halecium labrosum Alder, 1859
Halecium muricatum (Ellis et Solander, 1786)
Hydractinia carica Bergh, 1887
Lafoeina tenuis Van Beneden, 1847
Obelia hyalina Clarke, 1879
Obelia longissima (Pallas, 1766)
Perigonimus roseus Jäderholm, 1909
Phialella quadrata (Forbes, 1848)
Tubularia larynx Ellis et Solander, 1786

Alcyonacea soft coral
Alcyonium digitatum Linnaeus, 1758

Actinaria sea anemone
Urticina felina (Linnaeus, 1761)

Polycheta bristle worms
Hydroides norvegica (Gunnerus, 1768)
Pomatoceros triqueter (Linnaeus, 1767)

Gastropoda gastropods
Aporrhais pespelicanis Linnaeus, 1758
Buccinum undatum Linnaeus, 1758
Cryptonatica affinis (Gmelin, 1791)
Gibbula tumida (Montagu, 1803)
Hinia incrassata (Ström, 1768)
Lacuna pallidula (E. M. da Costa, 1778)
Lacuna vincta (Montagu, 1803)
Limacina helicina (Phipps, 1774) Pteropod
Margarites groenlandicus (Gmelin, 1791)
Margarites helicinus (Phipps, 1774)
Margarites olivaceus (T. Brown, 1827)
Neptunea despecta (Linnaeus, 1758)
Odostomia unidentata (Montagu, 1803)
Omalogyra atomus (Philippi, 1841)
Onoba semicostata (Montagu, 1803)
Patina pellucida (Linnaeus, 1758)
Skeneopsis planorbis (Fabricius, 1780)
Tectura testudinalis (O. F. Müller, 1776)
Tectura virginea (O. F. Müller, 1776)
Velutina velutina (O. F. Müller, 1776)

Bivalvia bivalves
Abra nitida (O. F. Müller, 1776)
Abra prismatica (Montagu, 1803)
Chlamys distorta (da Costa, 1778)
Chlamys islandica (O. F. Müller, 1776)
Crassadoma pusio (Linnaeus, 1758)
Heteranomia squamula (Linnaeus, 1758)
Hiatella arctica (Linnaeus, 1767)
Kellia suborbicularis (Montagu, 1803)
Lyonsia norvegica (Gmelin, 1791)
Modiolula phaseolina (Philippi, 1844)
Musculus discors (Linnaeus, 1767)
Mya truncata Linnaeus, 1758
Mytilus edulis Linnaeus, 1758
*Palliolum tigerinu*m (O. F. Müller, 1776)
Parvicardium pinnulatum (Conrad, 1831)
Spisula solida (Linnaeus, 1758)

Nudibranchia sea slugs
Acanthodoris pilosa (Abildgaard in O. F. Müller, 1789)
Adalaria proxima (Alder et Hancock, 1854)
Aeolidia papillosa (Linnaeus, 1761)
Ancula gibbosa (Risso, 1818)
Archidoris pseudoargus (Rapp, 1827)
Catronia aurantia (Alder et Hancock, 1854)
Dentronodus frondosus (Ascanius, 1774)
Doto coronata (Gmelin, 1791)
Doto pinnatifida (Montagu, 1804)
Eubranchus pallidus (Alder et Hancock, 1842)
Flabellina verrucosa (M. Sars, 1829)
Onchidoris bilamellata (Linnaeus, 1767)
Onchidoris muricata (O. F. Müller, 1776)
Tergipes tergipes (Forskal, 1775)

Crustacea/Amphipoda amphipods
Ampithoe rubricata (Montagu, 1808)
Apherusa jurinei H. Milne-Edwards, 1830
Calliopius laeviusculus Krøyer, 1838
Caprella linearis Linnaeus, 1767
Caprella septentrionalis Krøyer, 1838
Gammarellus angulosus (Rathke, 1843)
Gammarellus homari Fabricius, 1779
Gammaropsis nitida Stimpson, 1853
Hyperia galba (Montagu, 1813)
Hyperoche medusarum (Krøyer, 1838)
Ischyrocerus anguipes Krøyer, 1838
Jassa falcata (Montagu, 1808)
Metopa alderi (Bate, 1857)
Metopa borealis G. O. Sars, 1882
Metopa bruzeli (Goes, 1866)
Metopa pusilla G. O. Sars, 1892
Metopa rubrovittata G. O. Sars
Metopa solsbergi Schneider, 1884
Obelia geniculata (Linnaeus, 1758)
Parapleustes bicuspis (Krøyer, 1838)
Pleusymtes glaber (Boeck, 1861)
Stenothoe monoculoides (Montagu, 1813)

Crustacea/Isopoda isopods
Idotea granulosa Rathke, 1843
Idotea neglecta G. O. Sars, 1897
Idotea pelagica Leach, 1815

Janira maculosa Leach, 1814
Janiropsis breviremis G. O. Sars, 1899
Munna kröyeri Goodsir, 1842

Crustacea/Cirripedia acorn barnacles
Balanus balanus (Linnaeus, 1758)
Chirona hameri (Ascianus, 1767)
Semibalanus balanoides (Linnaeus, 1766)
Verruca stroemia O. F. Müller, 1776

Crustacea/Natantia shrimps
Crangon allmanii Kinahan, 1857
Eualus pusiolus (Krøyer, 1841)

Crustacea/Anomura squat lobster
Galathea nexa Embleton, 1834

Crustacea/Brachyura crabs
Hyas coarctatus Leach, 1815
Pagurus bernhardus (Linnaeus, 1758)
Pandalus montagui Leach, 1814
Polybius holsatus (Fabricius, 1798)

Crustacea/Copopoda copepod
Harpacticus arcticus Poppe, 1884

Pyconogonida sea spider
Nymphon hirtum Krøyer, 1844

Bryozoa bryozoans
Alcyonidium albidum Alder, 1857
Alcyonidium mamillatum Alder, 1857
Alcyonidium mytili Dalyell, 1847
Alcyonidium parasiticum (Fleming, 1828)
Alcyonidium polyoum Hassall
Amphiblestrum flemingi (Busk, 1854)
Arachnidium fibrosum Hincks, 1880
Bartensia gracilis (M. Sars)
Buskia nitens Alder, 1857
Callopora craticula (Alder, 1857)
Callopora dumerilii (Audouin, 1826)
Callopora lineata (Linnaeus, 1767)
Celleporella hyalina (Linnaeus, 1767)
Celleporina hassallii (Johnston, 1847)
Cribrilina annulata (Fabricius, 1780)
Cribrilina cryptooecium Norman, 1903
Cribrilina punctata Hassall, 1841
Cylindroporella tubulosa (Norman, 1868)
Diplosolen obelia (Johnston, 1838)
Electra pilosa (Linnaeus, 1768)
Escharella immersa (Fleming, 1828)
Flustra foliacea Linnaeus, 1758
Lichenopora hispida (Fleming, 1828)
Lichenopora verrucaria (Fabricius, 1780)
Membranipora membranacea (Linnaeus, 1767)
Membraniporella nitida (Johnston, 1838)
Microporella ciliata (Pallas, 1766)
Parasmittina trispinosa (Johnston, 1838)
Plagioecia patina (Lamarck, 1816)
Porella alba Noordgard, 1906
Porella minuta (Norman, 1868)
Porella smitti Kluge, 1907
Scizomavella linearis (Hassall)
Scruparia ambigua (d'Orbigny, 1841)
Scruparia chelata (Linnaeus, 1758)
Scrupocellaria elongata (Smitt, 1868)
Scrupocellaria scruposa (Linnaeus, 1758)
Tegella arctica (d'Orbigny, 1851)
Tegella unicornis (Fleming, 1828)
Tricellaria ternata (Ellis et Solander, 1786)
Tubulipora liliacea (Pallas, 1766)
Umbonula littoralis Hastings, 1944

Echinodermata/Asteroidea starfish
Hippasteria phrygiana (Parelius, 1768)
Asterias rubens Linnaeus, 1758

Echinodermata/Echinoidea sea urchins
Echinus esculentus Linnaeus, 1758
Strongylocentrotus droebachiensis (O. F. Müller, 1776)

Echinodermata/Ophiuroidea brittle star
Ophiopholis aculeata (Linnaeus, 1767)

Echinodermata/Holothurioidea sea cucumber
Cucumaria frondosa (Gunnerus, 1767)

Ascidiacea tunicates
Ascidia callosa Stimpson, 1852
Ascidia obliqua Alder, 1863
Boltenia echinata (Linnaeus, 1767)
Halocynthia pyriformis (Rathke in O. F. Müller, 1806)
Styela rustica (Linnaeus, 1767)

Pisces fish

Ammodytes tobianus Linnaeus, 1758	Sand eel
Cyclopterus lumpus Linnaeus, 1758	Lumpsucker
Limanda limanda (Linnaeus, 1758)	Dab
Liparis montagui (Donovan, 1804)	Montagu's sea snail
Lophius piscatorius Linnaeus, 1758	Anglerfish
Microstomus kitt (Walbaum, 1792)	Lemon sole

Appendix 9b.

Animals found in the sand at 16 to 125 m depths on the underwater slope of the volcano at Surtsey. Nephrops norvegicus* was fished at 140 to 160 m around Surtsey

Polychaeta bristle worms
Ammotrypane aulogaster Rathke, 1843
Anaitides groenlandica Oersted
Capitella capitata (Fabricius, 1780)
Diplocirrus glaucus (Malmgren, 1867)
Ditrupa arietina (O. F. Müller, 1776)
Sthenelais filamentosa Ditlevsen, 1917
Goniada maculata Oersted, 1843
Kefersteinia cirrata (Keferstein, 1862)
Nephtys hombergii Savigny, 1818
Owenia fusiformis delle Chiaje, 1841
Pectinaria koreni (Malmgren, 1866)
Pholoe minuta (Fabricius, 1780)
Scoloplos armiger (O. F. Müller, 1776)
Spio filicornis (O. F. Müller, 1766)
Spiophanes bombyx (Claparède, 1870)
Castalia punctata (O. F. Müller, 1788)
Eteone longa (Fabricius, 1780)
Lanice conchilega (Pallas, 1766)
Nephtys longisetosa Örsted, 1882
Scolelepis squamata (O. F. Müller, 1789)
Pseudopolydora antennata (Claparède, 1870)
Thelepus cincinnatus (Fabricius, 1780)

Crustacea/Amphipoda amphipod
Hippomedon denticulatus (Bate, 1857)

Crustacea/Brachyura crabs
Eurynome aspera (Pennant, 1777)
*Nephrops norvegicus** (Linnaeus, 1758)
Philocheras bispinosus (Hailstone, 1835)

Bivalvia bivalves
Abra nitida (O. F. Müller, 1776)
Abra prismatica (Montagu, 1808)
Acanthocardium echinatum (Linnaeus, 1758)
Arctica islandica (Linnaeus, 1767)
Macoma calcarea (Gmelin, 1791)
Spisula elleptica (Brown, 1827)

Echinodermata/Ophiuroidea brittle stars
Amphiura filiformis (O.F. Müller, 1776)
Ophiocten affinis (Lütken, 1858)

Echinodermata/Echinoidea sea urchin
Echinocardium flavescens (O. F. Müller, 1776)

Appendix 9c. Fish species found in the sea around Surtsey

Starry ray	*Amblyraja radiata* (Donovan, 1808)
Sand eel*	*Ammodytes tobianus* Linnaeus, 1758
Wolffish	*Anarhichas lupus* (Linnaeus, 1758)
Spotted catfish	*Anarichias minor* Ólafsson, 1772
Greater silver smelt	*Argentina silus* (Ascanius, 1775)
Tusk	*Brosme brosme* (Ascanius, 1772)
Basking shark	*Cetorhinus maximus* (Gunnerus, 1765)
Herring	*Clupea harengus* Linnaeus, 1758
Roundnose grenadier	*Coryphaenoides rupestris* Gunnerus,1765
Lumpsucker*	*Cyclopterus lumpus* Linnaeus, 1758
Common skate	*Dipturus batis* (Linnaeus, 1758)
Cod	*Gadus morhua* Linnaeus, 1758
Witch	*Glyptocephalus cynoglossus* (Linnaeus, 1758)
Long rough dab	*Hippoglossoides platessoides* (Fabricius, 1780)
Halibut	*Hippoglossus hippoglossus* (Linnaeus, 1758)
Megrim	*Lepidorhombus whiffiagonis* (Walbaum, 1792)
Dab**	*Limanda limanda* (Linnaeus, 1758)
Montagu's sea snail*	*Liparis montagui* (Donovan, 1804)
Anglerfish*	*Lophius piscatorius* Linnaeus, 1758
Capelin	*Mallotus villosus* (Müller, 1776)
Haddock	*Melanogrammus aeglefinus* Linnaeus, 1758
Whiting	*Merlangius merlangus* Linnaeus, 1758
Lemon sole*	*Microstomus kitt* (Walbaum, 1792)
Blue ling	*Molva dypterygia* (Pennant, 1784)
Ling	*Molva molva* (Linnaeus, 1758)
Plaice	*Pleuronectes platessa* Linnaeus, 1758
Saithe	*Pollachius virens* (Linnaeus, 1758)
Redfish	*Sebastes marinus* (Linnaeus, 1758)
Deep-sea rosefish	*Sebastes mentella* (Travin, 1951)

* Found sublittorally; listed also in App. 9a.
** Found both in the shallow sublittoral and deeper than 100 m; listed also in App. 9a.