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Vegetation cover on Icelandic thúfur.

RICHARD WEBB
Department of Botany, University College Swansea.*)

ABSTRACT: Description is given of the floral composition of Icelandic thúfur or frost mounds, and of the plant communities associated with them. A possible cyclic development of thúfur is outlined.

Thúfur are perhaps the most common microtopographical feature of the Icelandic landscape. They have been defined as "vegetation covered mineral cored mounds which have been originated by frost-action" (TROLL 1944). ". . . they occur together in numbers having a diameter of 0.5–2 metres and a height of 0.25–0.5 metres" (THORODDSEN 1914).

Their occurrence depends on such factors as poor drainage, clay soils, exposure to spring frosts and gentleness of slope. Thus main thúfur sites occur in areas which come under pressure from agriculture, and the regrowth of thúfur after ploughing is a great problem to the Icelandic farmers.

It appears that the construction of deep drainage ditches in susceptible areas seems to be the only answer at present to preventing their formation.

Most of the work was undertaken in the vicinity of the field research station at Víkurbakki which is about 30 km north of Akureyri. Location 18°18′ west–65°54′ north.

*) Most of the data for this work were collected on the expedition of the University College Swansea to the Eyjafjördur district of northern Iceland. It was largely due to the present lack of knowledge regarding thufur that the work was undertaken.

Several sites were examined and the vegetation type was found to be much the same in all of them. A more interesting site was finally chosen near to the field station as its proximity permitted ease of working.

The site had a 260° west facing slope of 4°16′ with a maximum slope of 7°. Although only 150 feet above sea level, the site was very exposed, owing to the treeless nature of the landscape and its location on a small morainic ridge overlooking the fjord which faces the Arctic Ocean.

The district is the driest in Iceland, being in a rain shadow belt sheltered by the surrounding mountains from the rain bearing south west winds. Average annual precipitation is around 480 mm. The coldest month is January ÷3.0°C. Over a metre of snow falls in the area. July is the warmest month with average temperatures of 10.9°C.

The land use is unimproved sheep grazing upon sub-arctic heath.

SOILS

In the area studied the soils are humified organic silts and loess to a depth of 50 cm overlying a white ash band. This can be correlated with the H3 tephra band dating this horizon at 2800 years B.C. This in turn overlays a grey brown peaty deposit. The soils can best be classed as azonal. The pH of the surface soil layers was measured to discover whether any variation occurred among the polygonal ground, thúfur crests and hollows, eroded flag and marsh which occurred in and around the area surveyed. All of these, however, showed a pH of 5–6.

VEGETATION ANALYSIS

At first it was hoped to carry out the survey on a statistical basis such as various forms of multivariant analysis and the drawing of plant constellations to find the degree of association between the species. This approach, however, raised the problem that any environmental differences brought out by these techniques at home obviously could not be re-examined in the field. Such an approach may yield interesting results however, and it is proposed to do this when resources allow.

In view of this it was decided to use the phytosociological approach to the problem even though the shortcomings of the method were realized.

Thúfur pose an interesting study into microhabitats which would repay closer investigation. A "minimal area" of ½ sq. metre was selected as the most convenient working size of quadrat.

The final species list includes the marsh and the polygonal ground areas below and above the thúfur.

Cladonia rangiferina
Cetraria islandica
Sphagnum teres
Drepanocladus uncinatus
Selaginella selaginoides
Botrychium lunaria
Equisetum arvense
Juncus sp.
Eriophorum angustifolium
Anthoxanthum odoratum
Nardus stricta
Festuca vivipara
Deschampsia ceaspitosa
Coeloglossum viride
Habenaria hyperborea
Luzula multiflora
Carex sp.
Thalictrum alpinum
Cerastium arcticum agg.
Armeria maritima
Tofieldia pusilla
Sedum villosum
Galium pumilum
Pyrola minor
Dryas octopetala
Potentilla crantzii
Veronica fruticans
Thymus arcticus
Bartsia alpina
Rhinanthus minor
Menyanthes trifoliata
Calluna vulgaris
Vaccinium uliginosum
Empetrum hermaphroditum
Silene acaulis
Viscaria alpina
Salix herbacea
S. lanata
Betula nana
Hieracium sp.
Erigeron borealis
Gentiana nivalis
Pinguicula vulgaris
Polygonum viviparum

The fifteen most common species were then plotted on a valency curve to find whether any degree of homogenity existed within the thirty-two sites of the stand. The resulting table shows that the area is approximately homogenous despite the paucity of species in the thúfur community which detracts from a better result. It is a simple community with only fifteen significant species which accounts for the absence of the 80%–100% group in the table.

The vegetation transect was taken down from the top of the ridge, on the micropolygonal ground, across the thúfur, and out onto the marsh at the foot of the slope, a distance of 216 feet. The slope and the larger thúfur hummocks were levelled as accurately as possible. Every four feet along the transect the vegetation was sampled within

TABLE 1. *Valence Table of Thúfur Vegetation*

% Occurrence	% No. Species	Species
0 – 20	41	*Galium pumilum* *Pinguicula vulgaris* *Habenaria hyperborea* *Tofieldia pusilla* *Luzula* sp.
20 – 40	22	*Alchemilla alpina* *Polygonum viviparum* *Thymus arcticus* *Salix herbacea*
40 – 60	22	*Vaccinium uliginosum* *Calluna vulgaris* *Thalictrum alpinum* *Carex* sp.
60 – 80	10	*Empetrum hermaphroditum* *Dryas octopetala*

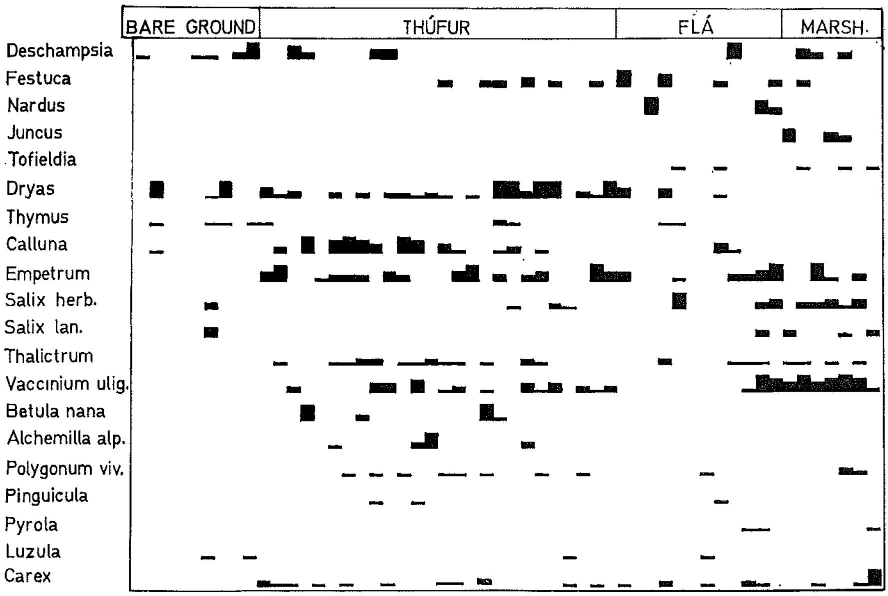

FIGURE 1. Vegetation transect on thúfur.

TABLE 2. *Thúfur Association Table (150 ft. above sea level). Calluna–Empetrum* Association

Constancy	Species	1	2	3	4	5	6	7	8	9	10	11
5	Empetrum hermaphroditum	9	4	5	6	5	4	3	3	4	5	5
5	Vaccinium uliginosum	6	4	5	3	4	5	4	4	—	5	4
5	Dryas octopetala	6	—	5	6	5	3	2	5	8	5	5
5	Calluna vulgaris	5	5	9	5	4	4	8	5	4	4	4
5	Thalictrum alpinum	1	1	3	3	3	2	2	2	2	2	2
5	Polygonum viviparum	2	1	1	2	2	2	2	2	2	2	2
5	Thymus arcticum	1	—	2	2	2	2	2	3	1	2	—
3	Carex bigelowi	1	—	—	—	—	—	1	—	—	—	1
4	Salix herbacea	—	2	2	1	1	1	1	—	—	3	—
2	Galium pumilum	1	—	—	1	1	—	—	1	—	—	—
2	Pinguicula vulgaris	—	—	—	—	1	1	—	—	—	—	—
2	Habenaria hyperborea	—	—	1	1	—	1	—	—	1	—	1
4	Betula nana	1	1	4	1	—	1	—	1	1	—	1
5	Festuca vivipara	5	3	3	4	4	3	—	3	2	4	3
2	Nardus stricta	—	—	—	—	—	4	3	—	—	2	—
2	Luzula multiflora	—	—	1	—	—	—	—	2	—	—	—
1	Silene Acaulis	—	—	—	—	—	—	—	—	—	—	—
2	Tofieldia pusilla	—	—	—	—	1	1	—	1	—	—	1
2	Selaginella selaginoides	—	1	—	—	1	—	—	1	—	—	—
2	Cladonia rangiferina	—	—	—	1	—	—	—	—	2	—	—
5	Alchemilla alpina	2	8	1	2	1	4	3	5	—	1	1

Constancy	Species	12	13	14	15	16	17	18	19	20	21
5	Empetrum hermaphroditum	17	13	7	2	5	4	6	4	4	5
5	Vaccinium uliginosum	4	1	4	3	5	5	—	5	4	4
5	Dryas octopetala	5	7	—	5	2	5	6	4	1	6
5	Calluna vulgaris	3	4	6	4	5	6	1	6	6	6
5	Thalictrum alpinum	2	2	1	2	1	1	1	1	2	2
5	Polygonum viviparum	2	2	1	2	1	2	1	2	2	3
5	Thymus arcticum	2	2	4	3	1	2	3	2	2	3
3	Carex bigelowi	—	—	2	2	1	2	3	2	1	1
4	Salix herbacea	—	3	2	1	2	2	—	3	3	2
2	Galium pumilum	—	1	1	—	—	1	—	—	—	—
2	Pinguicula vulgaris	1	1	—	1	2	1	—	1	—	—
2	Habenaria hyperborea	—	3	—	—	—	1	—	—	—	—
4	Betula nana	3	—	1	—	—	—	—	1	2	1
5	Festuca vivipara	3	3	2	3	2	3	3	1	2	1
2	Nardus stricta	—	—	1	—	—	3	—	3	3	2
2	Luzula multiflora	1	—	—	—	—	—	1	2	1	—
1	Silene Acaulis	—	—	1	—	—	—	1	—	—	—
2	Tofieldia pusilla	—	—	—	—	—	1	—	—	1	—
2	Selaginella selaginoides	1	1	—	—	—	—	1	—	—	—
2	Cladonia rangiferina	—	—	2	—	3	—	—	1	—	—
5	Alchemilla alpina	3	5	1	5	4	—	6	3	—	1

a ¼ metre quadrat. All species present were assessed on cover using a modified Braun-Blanquet scale.

Some species such as *Carex* are ubiquitous throughout the transect. It shows various species such as *Thalictrum, Vaccinium* and *Polygonum* coming in as the thúfur are reached. *Dryas, Thymus* and *Calluna* do not occur on the marsh whereas the *Vaccinium, Salix* and *Juncus* increased in importance. The transect is useful in showing to some degree the importance of the various thúfur community species (Fig. 1).

TABLE 3. *Upland Thúfur Association Table (1800 ft.).*
Empetrum—Salix Association

Constancy	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	Empetrum hermaphroditum	7	4	7	7	7	6	3	6	5	5	6	4	6	5	5
2	Alchemilla alpina	—	—	—	1	—	—	4	5	—	—	—	4	—	4	—
5	Vaccinium myrtillus	4	4	4	5	2	5	4	5	4	8	5	—	1	8	7
4	V. uliginosum	4	—	3	4	3	6	3	—	—	4	3	—	5	—	4
1	Thymus arcticus	—	—	—	—	—	—	—	—	2	—	—	—	3	—	—
3	Loiseleuria procumbens	—	—	3	6	—	4	—	—	6	2	1	4	—	—	—
5	Salix herbacea	5	5	5	5	3	4	3	6	5	3	4	3	1	5	4
1	S. glauca	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	Silene acaulis	—	—	—	—	4	—	—	—	—	—	—	2	—	—	—
1	Taraxacum officinalis	1	—	—	—	1	—	3	—	—	—	—	—	—	—	—
5	Polygonum viviparum	—	3	3	2	3	1	4	1	2	2	1	3	3	3	1
4	Thalictrum alpinum	—	3	3	2	—	—	1	2	3	3	2	—	3	1	2
1	Cassiope hypnoides	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—
1	Bartsia alpina	—	—	—	—	—	—	—	—	—	—	—	1	4	—	—
1	Galium pumilum	—	—	—	—	1	—	—	—	1	—	—	—	—	—	2
1	Coeloglossum viride	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1	Tofieldia pusilla	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
5	Drepanocladus uncinatus	6	—	2	—	6	3	5	5	3	4	4	—	4	5	2
1	Bartramia pomiformis	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
2	Rhacomitrium canescens	—	—	—	—	—	—	—	—	1	—	—	4	4	—	1
3	Polytrichum juniperinum	—	2	—	2	1	—	5	2	—	—	3	—	—	1	—
4	Cladonia rangiferina	—	5	1	2	3	3	1	—	4	5	—	5	4	—	8
4	Cetraria islandica	—	2	1	2	1	4	1	—	3	1	3	3	2	—	1
2	Cladonia sp.	—	1	—	1	1	1	—	—	1	—	—	—	—	—	1
5	Fustuca ovina	4	3	5	1	2	4	4	5	4	4	3	3	3	3	3
3	Anthoxanthum odoratum	—	—	3	—	—	2	—	3	3	2	3	2	2	—	1
3	Juncus	—	3	—	1	1	—	—	—	—	3	—	1	2	—	4
5	Carex sp.	2	2	2	1	2	4	2	1	3	3	2	2	4	1	4
1	Selaginella selaginoides	—	2	—	2	—	—	1	—	—	—	2	—	1	—	—
4	Equisetum sp.	—	2	1	1	1	1	—	1	3	1	—	5	—	—	1
1	Peltigera	—	—	—	—	—	—	1	—	1	—	—	—	—	—	3

This was carried further by the construction of association tables. Twenty-one sites were randomly sampled using the ½ m size quadrat earlier chosen as the "minimal area." The cover values were assessed, this time on the more accurate Domin scale. The "degree of constancy" was then worked out and this was taken to show the two most important species in the association, namely *Calluna vulgaris* and *Empetrum hermaphroditum*. This in fact was not readily apparent from observations.

This was compared with an association table drawn from thúfur on a flat east facing ledge at 1,800 feet on Kötlufjall. The species were more numerous as one had an intermingling of plants characteristic of higher altitudes such as *Cassiope hypnoides, Salix glauca* and *Loiseleuria procumbens*. The more important species here was also *Empetrum* but *Salix herbacea* replaced the *Calluna,* which by this time had disappeared entirely.

At this altitude the thúfur appeared to be semewhat larger and more developed than those at 150 feet, probably due to a more intensive frost action.

It was curious to note that a much more vigorous growth of *Vaccinium myrtillus* occurred on the west side of the hummocks than on the east side which appeared to support more *Salix*. The factors responsible for such a phenomena were not apparent during the short time in which the data were collected, but it may be due partly to differential snow cover and insolation.

In an attempt to obtain a more detailed picture of the species comprising the thúfur community, in terms of spatial and vertical distribution, two charts were made covering an area of four square metres. An accurately surveyed microcontour chart gave the dimensions of the hummocks and hollows. This formed the basis of a vegetation map charted on ½ m quadrats. This proved too complex to include in print but the major points are discussed below.

The thúfur crests are drier in summer than the hollows in which the soil is also more compacted. The crests are also, to a large extent, swept free of snow by wind in the winter, and so they are more subjected to frost action and large changes in temperature than the sheltered hollows. The crests of the thúfur carried mats of *Dryas octopetala* which seem to dominate such extreme habitats. The flanks were covered with *Calluna, Empetrum* and *Vaccinium*. It was striking to note that the hollows between the thúfur were occupied almost exclusively by *Alchemilla alpina* and *Polygonum viviparum*. This was further supported by a profile chart drawn across a distance of

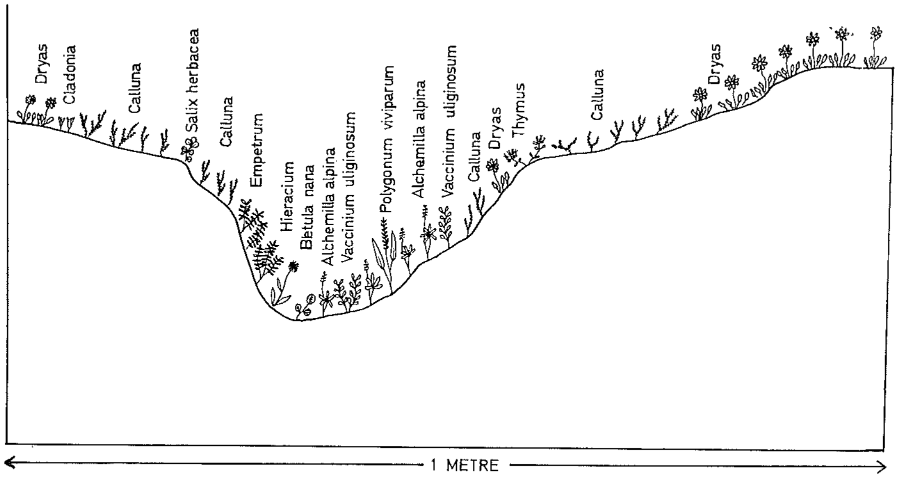

FIGURE 2. Profile chart of thúfur. 3 cm sampling over 1 metre.

a metre, between two hummock crests, in which the same sequence of species can be observed (Fig. 2).

This sequence was compared with observations of the thúfur at 1800 ft. Here the thúfur crests were dominated by *Loiseleuria procumbens* with some *Dryas*. The hollows supported more *Hieraciums* and grasses than those of the lower site. *Rhacomitrium canescens* was also more apparent in the hollows on the higher site.

During these investigations it became apparent that the development of thúfur may be under the influence of a cyclic process of events. It was observed that on bare, stony areas which are characterized by micropolygons of stones, there occur patches of *Dryas* which often grow in the lee of large stones. These cushions become colonized by *Thymus arcticus*, *Salix* sp. and *Silene acaulis* until a small hummock is built up. By a process of differential insulation, outlined by HOPKINS and SIGAFOOS in 1954, the hummocks increase in size and usually merge into areas of thúfur. When the thúfur reaches a critical size, governed by the availability of soil moisture, its crest projects above the winter snow cover. This makes the crest vegetation available for grazing during winter. Once the insulating cover of vegetation has been removed by grazing then needle ice formation can occur and the soil is broken up. The centre can be completely excavated by this process. The old flanks are left to form new thúfur while the hollows become colonized by *Betula nana*. The process then continues and thúfur areas in many parts of Iceland are characterized by crescent shaped or similarly eroded thúfur.

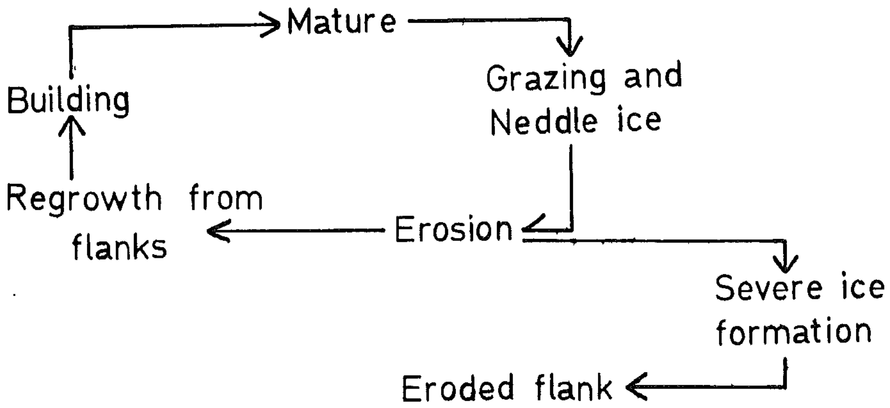

FIGURE 3. A cyclic process in thúfur development.

It is not yet known how many years the cycle takes to complete. The minimum age of the thúfur was tentatively assumed by counting the number of annual rings in the stems of *Betula nana,* which was found to be the most useful species for this work. Ten dwarf birches were sampled in each plot.

These figures were subjected to analysis of variance which showed that they were significantly different. This indicates that the marsh thúfur are the youngest and also the smallest sampled. The larger

TABLE 4. *Age of Dwarf Birches Sampled From Different Types of Thúfur.*

	Marsh thúfur	Large thúfur	Thúfur at top of slope
a)	8 years	11 years	10 years
b)	7 –	11 –	24 –
c)	8 –	12 –	17 –
d)	8 –	13 –	10 –
e)	9 –	14 –	13 –
f)	8 –	13 –	10 –
g)	8 –	12 –	20 –
h)	9 –	15 –	15 –
i)	9 –	10 –	16 –
j)	8 –	14 –	24 –
	Average 8.2 years	12.5 years	15.9 years

thúfur have grown comparatively rapidly and erosion may occur after about thirteen years. The complete cycle may thus operate over a twenty-five year period. It is hoped to examine the cyclic process of thúfur development tn the light of recent research into the matter, in a later article.

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