Fallout Radionuclide Distribution in Lichen Communities near Thule

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ABSTRACT. Concentrations of the worldwide fallout radionuclides manganese-54, zinc-65, strontium-90, cesium-137, and cerium-praseodymium-144, and naturally-occurring potassium-40 were measured in 80 lichen species collected near Thule, Greenland, during July-August 1968. Emphasis was placed on ^{137}Cs for detailed comparison of radionuclide distribution within the 6 major and 5 minor lichen communities of the 1,500 km.^{2} area studied. Mean ^{137}Cs concentrations in major lichen species ranged from 22 picocuries per gram standard dry weight in *Stereocaulon paschale* to 50 pCi/g. in *Cornicularia divergens,* with an overall average of 33 pCi/g. Significant differences were noted between species, habitats and world regions.

RÉSUMÉ. *Distribution des radionucléi de retombée dans les associations lichénique près de Thulé.* En juillet-août 1968, on a mesuré les concentrations mondiales des radionucléi de retombée manganèse-54, zinc-65, strontium-90, césium-137 et cérium-praséodymium-144, et du potassium-40 naturel, dans 80 espèces de lichens recueillis près de Thulé, Groenland. L'étude a surtout porté sur le ^{137}Cs, pour une comparaison détaillée de la distribution des radionucléi à travers les 6 associations lichéniques majeures et les 5 associations mineures de l'aire étudiée (1,500 km^2). Les concentrations moyennes de ^{137}Cs dans les espèces lichéniques majeures variaient de 22 picocuries par gramme de poids normal à sec dans *Stereocaulon paschale,* à 50 pCi/g dans *Cornicularia divergens,* avec une moyenne générale de 33 pCi/g. On a noté des différences significatives entre les espèces, les habitats et les régions du monde.

РЕЗЮМЕ. *Распределение радиоактивных изотопов в лишайниковых сообществах в районе Тулэ (Гренландия).* Были измерены концентрации радиоактивных выпадений ^{54}Mn, ^{65}Zn, ^{90}Sr, ^{137}Cs, ^{144}Ce-Pr, а также природного ^{40}K в 80 видах лишайников в районе Тулэ. Измерения проводились в июле и августе 1968 г., особое внимание уделялось концентрации ^{137}Cs для детального сравнения распределения радиоактивных изотопов в шести крупных и пяти мелких лишайниковых сообществах в исследованном районе площадью 1500 км^2.

INTRODUCTION

During July and August 1968 an investigation of fallout radionuclides in the environs of Thule, Greenland, was made by a Danish-American expedition that studied environmental consequences of a United States Air Force bomber crash there (Aarkrog 1970). Terrestrial aspects of that investigation included collection and analyses of lichen samples for various radionuclides because of their demonstrated abilities to retain appreciable amounts of such material (Gorham 1959;

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Hanson 1967a). It also afforded a unique opportunity to obtain information that could be compared with radiation ecology studies conducted in northern Alaska and other circumpolar regions.

PROCEDURES

Eighty samples of foliose and fruticose lichens were collected from 27 sampling sites in the Thule region during the period 26 July to 26 August 1968. Ten samples were sufficiently uniform to permit collection on an areal basis (0.25 to 0.40 sq. m.) and thus to allow estimates of productivity and total fallout radionuclide retention. Samples were air dried at Thule and returned to the home laboratory, where they were moisturized and meticulously hand-separated into the various lichen species, vascular plants, plant debris, and soil that normally comprise a lichen community. This was necessary to make interspecific comparisons at various sampling locations and to remove extraneous material that would modify true weights and radionuclide determinations. The components were dried to constant weight at 70°C. for 48 hours to determine percentage of the total community. The lichens were then separately ground in a Wiley mill and aliquots processed according to standard procedures (AOAC 1965) to obtain standard dry and ash weights. Gamma-emitting radionuclides were measured in a nominal 23 x 28 cm. Na(T1) crystal with a 7.7 x 15 cm. well, connected to a 400-channel gamma analyser-spectrometer. Data were reduced by an electronic computer program designed to yield results for naturally-occurring potassium-40 and seven radionuclides commonly encountered in worldwide fallout. All lichen species from each community sample were then mixed and again measured for gamma-emitters. The term community included all lichen species (populations) within a sample, which was then designated by the dominant lichen species at that location. The dominant species contributed an average of 90 per cent of the lichen biomass in the 80 samples obtained and the remainder consisted of varying amounts of several species.

RESULTS

Cetraria nivalis was the most commonly observed fruticose lichen community of the Thule region and served as a standard for comparison with other lichen species and as an indicator of radionuclide distribution in the environment. It was collected at 22 of 27 sampling locations (Fig. 1). Five other major lichen communities were represented in the region; one or more samples were obtained of *Stereocaulon paschale* at 10 locations, *Alectoria ochroleuca* at 7, *Cetraria cuculata* at 6, and *Cetraria delisei* and *Cornicularia divergens* each at 5 locations. In addition, 2 samples of *Cornicularia nigricans* and single samples of *Neuropogon sulphureus, Thamnolia vermicularis, Umbilicaria* spp. and *Peltigera* sp. were collected.

Measurable amounts of the fallout gamma-emitters, manganese-54, zinc-65, cesium-137 and cerium-praseodymium-144 and the naturally radioactive potassium-40 were present in nearly all lichen samples.

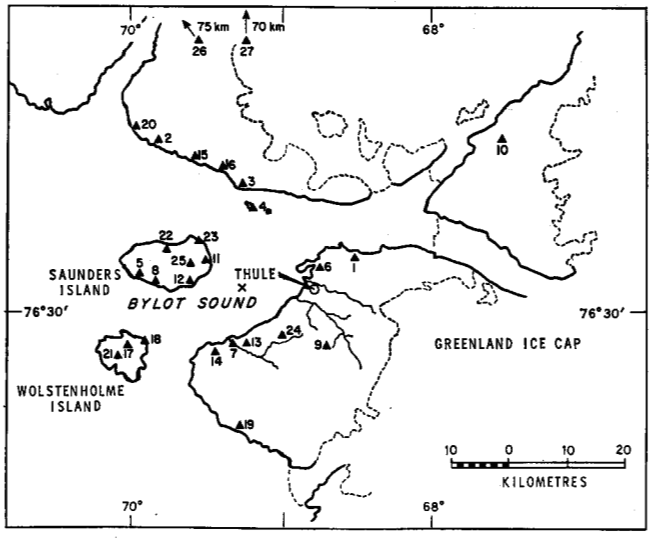

FIG. 1. Map of Thule District, North Greenland, showing lichen sampling locations.

Using ^{137}Cs as a standard for comparison of radionuclide ratios, the following ranking was observed:

$$^{54}Mn: {}^{137}Cs = 0.08$$
$$^{40}K: {}^{137}Cs = 0.20$$
$$^{65}Zn: {}^{137}Cs = 1.00$$
$$^{144}Ce\text{-}^{144}Pr: {}^{137}Cs = 1.08$$

Strontium-90, a beta emitter, was present in 79 lichen samples at a concentration of 0.24 that of ^{137}Cs. These ratios were consistent with results obtained in northern Alaska (Hanson and Eberhardt 1971, *in press*) and in southwestern Greenland (Aarkrog and Lippert 1969) near the same time. This indicated a normal complement of fission products from stratospheric fallout and provided convenient tags for radiation ecology studies. Emphasis was placed on ^{137}Cs for detailed examination because it has been extensively studied in circumpolar regions.

Greatest ^{137}Cs concentrations were usually found in *Umbilicaria, Cornicularia* and *Alectoria* communities, median values in *Cetraria* and *Neuropogon* species, and consistently lower values occurred in *Stereocaulon, Peltigera* and *Thamnolia* (Table 1).

TABLE 1. Comparison of mean ^{137}Cs concentrations in 8 lichen genera.

Genera	No. Samples	Mean ^{137}Cs Concentration pCi/g. standard dry weight
Umbilicaria	1	56
Cornicularia	8	50
Alectoria	10	44
Cetraria	46	34
Neuropogon	1	33
Stereocaulon	12	23
Peltigera	1	21
Thamnolia	1	11

Statistical analysis of ^{137}Cs levels in multiplicate samples of 6 lichen species was performed by normalizing the data by logarithmic transformation (Eberhardt 1964) and determining significant differences by analysis of variance. Duncan's multiple range test was used to compare the means of the various species (Table 2).

TABLE 2. Comparison of mean ^{137}Cs concentrations in major lichen species.

Species	No. Samples	Cesium-137 Concentrations in pCi/g standard dry weight Geometric Mean	*	.95 Confidence Limits	
				Lower	*Upper*
Cornicularia divergens	8	50.0	A	37.1	57.4
Alectoria ochroleuca	10	44.0	A	39.1	49.6
Cetraria delisei	6	36.6	AB	23.9	56.0
Cetraria cuculata	6	32.8	B	22.5	47.6
Cetraria nivalis	34	32.2	B	29.6	35.0
Stereocaulon paschale	12	22.0	C	18.3	26.3
All species	76	33.0			

*Duncan's multiple range test results; means with different letters are significantly different at .05 level.

Similar examination of ^{137}Cs concentration in *C. nivalis,* all other lichen species, and plant debris from various habitats in the Bylot Sound region showed significantly higher amounts on Saunders and Wolstenholme Islands compared to surrounding shoreline and mainland habitats (Table 3). Lowest values, about one-third the maximum concentrations, were associated with the dry, rocky moraine at Nunatarssuaq (Location 10) and on the arid hillsides near Narssarssuk and Kap Atholl (Locations 13, 14 and 19). Strontium-90 concentrations showed much the same geographic distribution as ^{137}Cs values. The difference between the habitats is partly explained by the greater occurrence of *S. paschale* communities, low in ^{137}Cs concentrations, in the mainland habitats; whereas a majority of the *C. divergens* and *A. ochroleuca* communities, with high ^{137}Cs concentrations, were associated with the islands. There was no apparent rationale to explain the higher values on the islands, unless the substantial winds of the Thule region significantly affected the fallout deposition by rearranging the snowfall. The greater concentrations of fallout material in plant debris than in the lichens from which it was separated was attributed to dead material containing fallout materials deposited in earlier years when fallout deposition was greater, the slow breakdown of the litter, and the more dynamic translocation of elements by the lichens.

Plant debris was uniformly distributed through the samples at a mean mass of 0.16 that of the lichen component. Broken lichen parts made up a substantial portion and the remainder was composed of mosses (*Lycopodium* spp. and *Selaginella* spp.) or leaves of willow *(Salix arctica),* Labrador tea *(Ledum palustre),* heather *(Cassiope tetragona),* saxifrage *(Saxifraga oppositifolia),* avens *(Dryas intergrifolia),* and sedges *(Carex* spp.). Much of the vascular plant debris appeared to have been accumulated over considerable time, and formed a cushion near the base of the lichen communities. Samples of vascular plants were not collected

except for one large sample (2 m.^{2}) of the 1968 seasonal growth of arctic timothy *(Alopecurus alpina)* from the Eiderduck Islands located between Saunders and Wolstenholme Islands; it contained 3.1 pCi ^{137}Cs/g. and 43 pCi ^{40}K/g., or about one-tenth the ^{137}Cs concentration and about ten times as much ^{40}K, compared with lichens.

Standing crops of lichens in 10 places that permitted realistic areal sampling yielded 380 ± 30 (S.E.) grams standard dry weight per square metre in the *C. nivalis* communities and 340 ± 20 (S.E.) g./m.^{2} in the *A. ochroleuca* communities. Single samples of *C. delisei* and *S. paschale* yielded 580 and 1,000 g./m.^{2}, respectively. Total radionuclide content of these lichen community components are shown in Table 4. The ratios of the radionuclides are near those quoted earlier for the numerous individual samples, but with limited confidence in the single values from the *C. delisei* and *S. paschale* communities.

DISCUSSION

The fruticose lichen communities of the Thule region were discontinuously distributed over the landscape and this precluded the intensive sampling desired; however, the data illustrate the important influence of ecological parameters upon radionuclide concentrations. The lichen communities (samples) individually consisted of 6 to 10 lichen species growing in concert and which contained variable amounts of radionuclides as they competed for fallout and other materials. Vascular plant and lichen debris represented 3 to 36 percent as much mass as the lichens, and about half of the samples contained appreciable amounts of windblown soil and rocks that contributed variable mass and radionuclide concentrations. The samples, therefore, represented a complex *mélange* that warranted the tedious separation of the components so that realistic comparisons could be made with lichen samples obtained in northern Alaska as part of our long-term radiation ecology studies (Hanson *et al.* 1967; Hanson 1967b) and those in northern Scandinavia (Lidén and Gustafsson 1967; Miettinen and Häsänen 1967). The use of data from unseparated bulk samples would have precluded many of the comparisons and evaluations of ecological significance, such as those made in Tables 3 and 4.

TABLE 3. Comparisons of ^{137}Cs concentrations in *C. nivalis,* all other lichens, and plant debris from various habitats of the Thule, Greenland region (G.M. = Geometric Mean; C.L. = Confidence Limits in units of picocuries ^{137}Cs per gram standard dry weight).

	Saunders and Wolstenholme Islands			*All Mainland*		
Sample Type	No.	G.M.	.95 C.L.	No.	G.M.	.95 C.L.
C. nivalis	17	36.9	34.7—39.2	17	28.1**	24.6—32.0
Other lichens	25	37.2	35.0—39.5	55	30.4*	27.3—33.7
Plant debris	25	42.4	36.3—49.5	55	31.6*	27.8—36.0

*Mean significantly different from corresponding Islands mean at .05 level.
**Mean significantly different from corresponding Islands mean at .01 level.

TABLE 4. Fallout radionuclide content of Thule, Greenland lichen community components, summer 1968.

Lichen Community Component	N	Std. dry wt. g/m²	Radionuclide Content (nCi/m²) ^{54}Mn	^{65}Zn	^{90}Sr	^{137}Cs	^{144}Ce-Pr
C. nivalis							
lichens	4	380	0.8	1.0	4.9	12.0	13.2
debris	4	94	0.13	0.6	0.9	4.9	3.4
soil	1	23	N.D.	N.D.	N.A.	0.6	N.D.
A. ochroleuca							
lichens	4	340	0.07	2.3	2.6	13.3	17.6
debris	4	27	0.2	0.1	0.4	1.1	0.5
soil	1	24	N.D.	N.D.	N.A.	0.5	N.D.
C. delisei							
lichens	1	580	1.9	0.9	1.4	25.0	11.5
debris	1	92	N.D.	0.8	1.0	5.4	6.9
soil	1	tr					
S. paschale							
lichens	1	1000	N.D.	1.6	4.7	20.0	14.9
debris	1	160	N.D.	N.D.	0.6	2.6	2.5
soil	1	tr					

N.A. = Not Analysed; N.D. = Not Detected.

Several environmental factors obviously exert great influence on the lichen productivity and distribution in the Thule region. Most lichens were found in rills, stone stripes and nets or other irregular surface features that provided moisture, sites for organic matter accumulation and shelter from the substantial winds. Moisture appeared to be one of the more apparent limiting factors for both plant growth and fallout deposition. Annual precipitation at Thule during the period 1960 to 1967 averaged 13 cm., compared to 32 cm. at Fairbanks, Alaska (Hardy and Rivera 1969) which serves as the data source for our studies in that region. This disparity in precipitation was especially important to radionuclide deposition during and immediately following the 1961-1962 period of atmospheric nuclear weapons tests. The data are expressed in terms of ^{90}Sr deposition, which is the standard of measurement for fallout deposition, but may be converted to ^{137}Cs deposition by the use of the ratio ^{137}Cs: ^{90}Sr = 1.9 $\pm$ 0.2 (Hardy and Chu 1967).

The amount of ^{137}Cs retained in Thule lichen communities (Table 4) was about half that in northern Alaskan *Cladonia-Cetraria* mats (28 nCi/m.²) during the summer of 1968. This is partially explained by the greater fallout deposition and biomass of lichens in Alaska (1,600 g./m.²) compared to the Thule *Cetraria* and *Alectoria* communities (380 and 340 g./m.², respectively). Vascular plants and debris in the Thule lichen communities contained about 20 per cent as much ^{137}Cs as the lichen components, compared to 2 to 3 per cent in Alaskan samples, emphasizing the low biomass per unit area and the importance of separating the components for individual examination.

Total radionuclide content of the 10 lichen communities for which areal sampling was suitable averaged 44 nCi/m.², of which 83 per cent was concentrated in the lichen component, 17 per cent in the vascular plants and debris, and <1 per cent in the soil and rocks. Contributions of the 4 radionuclides listed in Table 3, within the lichen and vascular plant fractions were: 44 per cent from

^{137}Cs, 37 per cent from ^{144}Ce-Pr, 8 per cent from ^{90}Sr, 6 per cent from ^{65}Zn and 4 per cent from ^{54}Mn. Coefficients of variation for these radionuclides were generally about 0.15 for ^{90}Sr, ^{137}Cs and ^{144}Ce-Pr, but varied from 0.25 to 0.60 for ^{54}Mn and ^{65}Zn. Eberhardt (1964) reported an average C.V. of about 0.35 for ^{137}Cs in an extensive series of arctic plant and animal samples. The lower values in this report may be due to the small number of samples compared.

Structural differences and ecological niche of lichens were evidently important factors in determining radionuclide concentration ranking of the various species. *Cornicularia* and *Alectoria* had the highest ^{137}Cs concentrations and are richly branched species that often colonized ridges and formed simpler communities than the *Cetraria* species. *Cetraria delisei,* the so-called "snowpatch lichen" because of its association with drift areas, may have accumulated greater amounts of ^{137}Cs released from melting snow than were available to other *Cetraria* species. *Stereocaulon* and *Thamnolia* species contained the least concentrations of ^{137}Cs and tend to be structurally simpler and less branched than other lichens studied. These observations pose problems for interpretation and offer areas of inquiry for further evaluation.

CONCLUSIONS

Lichen communities within a 1,500 km.^{2} area surrounding Thule, Greenland, during the summer of 1968 contained worldwide fallout radionuclides similar in nature and ratios to those found in northern Alaska. Total amount on an areal basis was one-half that in Alaska, primarily because of less fallout deposition and biomass of lichens per m.^{2} in northern Greenland. Significantly different ^{137}Cs concentrations among 6 lichen species and 2 major habitats emphasized the importance of climatic factors, ecological niche and structural diversity in influencing the radionuclide distribution within the Thule lichen communities.

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