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CYCLING AND COMPARTMENTALIZING OF RADIONUCLIDES IN NORTHERN ALASKAN LICHEN COMMUNITIES [1]

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DISCLAIMER

ABSTRACT

Cycling of cesium-137 and other fallout radionuclides in natural lichen communities of Northern Alaska was studied by periodic sampling on a year-round basis during the period 1964-1969. Maximum concentrations usually occurred during summer months and minima during winter months. Vertical strata of lichens, humus and soil taken at those times showed pronounced seasonal shifting of radionuclides between community components. These data partially account for the sudden increase in cesium-137 body burdens of northern Alaskan caribou during spring months of each year and have important implications in the Eskimo populations dependent upon the caribou for basic food.

Cycling and Compartmentalizing of Radionuclides In Northern Alaskan Lichen Communities

INTRODUCTION

Lichen communities have long been recognized as the basic reservoir of natural and artificial radionuclides from which efficient transfer to caribou/reindeer and arctic peoples has resulted in appreciable concentrations in the upper trophic levels. Most circumpolar studies have also emphasized the long retention times for certain radionuclides, especially cesium-137. Effective half-lives of ^{137}Cs in lichens have been reported to range from 4-5 years (Miettinen and Häsänen 1967) to greater than 10 years (Lidén and Gustafsson 1967; Hanson, Watson and Perkins 1967; Hanson and Eberhardt 1969). The half-time of strontium-90 in lichens has received less study because of its apparent lesser importance in the arctic food chain; it has generally been reported to be more mobile than ^{137}Cs (Nevstrueva et al. 1967).

Our studies of radionuclides in northern Alaskan ecosystems have previously reported the seasonal cycle of ^{137}Cs in caribou and Eskimos which primarily depends upon the dietary shifts of both trophic levels in a relatively simple system. The deceptive nature of modelling such a system subject to environmental parameters has been discussed in an earlier paper (Eberhardt and Hanson 1969). One aspect of these studies that has concerned us has been the consistent and impressively abrupt increase of ^{137}Cs concentrations in caribou (Rangifer tarandus) flesh samples collected annually during the spring migration of animals from their winter range to the summer range. We had ascribed it to the movement of the caribou to ranges containing greater ^{137}Cs

concentrations than during preceding months or to sampling variability (Hanson 1966). We have evaluated these possibilities and believe they can be ruled out as the major cause of the anomaly and present initial evidence of radionuclide cycling in lichens that has not been previously reported and which explains the phenomenon.

METHODS

The intensive lichen studies were conducted in the vicinity of Anaktuvuk Pass, Alaska (68° 10'N, 151° 46'W) during the period January 1964 - August 1970, with a temporary interruption during the period August 1965-April 1966. Winter range lichens were also collected twice annually at three locations on the southern edge of the Brooks Range mountains: Kanuti River (66° 25'N, 152° 00'W), Pah River (66° 30'N, 155° 32'W) and Tagagawik River (66° 17'N, 159° 05'W) (Figure 1). The period of study began almost simultaneously with the major period of fallout deposition, as measured at Fairbanks, Alaska (64° 49'N, 147° 52'W), some 400 km southeast of Anaktuvuk Pass (Hardy 1971) as shown in Figure 2. Strontium-90 deposition rate ($mCi/km^2 = nCi/m^2$) at Anaktuvuk Pass was considered to be about two-thirds that at Fairbanks on the basis of differences in annual precipitation (30 cm vs 20 cm) (Watson 1959). Cesium-137 deposition was calculated from the ratio ^{137}Cs: $^{90}Sr = 1.9 \pm 0.2$ (Hardy and Chu 1967).

Samples collected at Anaktuvuk Pass during the first five time intervals were obtained from the same general area selected in July 1964 for the site of radionuclide half-time studies (Hanson and Eberhardt 1969). Two similar locations on gently rolling terrain were routinely sampled, one a gridded control plot adjacent to our "tagged" area for artificial radionuclide half-time studies and the

other in a nearby snow accumulation area. Fruticose lichen samples were collected from 0.25 or 0.5m^2 areas of nearby uniform communities. Vascular plants were separated from the lichens, which included the "slime area" just above the humus layer underlying the communities. During winter, 0.6-0.8m of frozen snow covering the lichens was removed by shovel, which was also used to cut out the 0.25m^2 of frozen lichens. These samples were placed in large plastic bags to maintain sample form until they were later thawed and processed into components.

Stratified samples were removed with an ice chisel and divided into upper 6cm of lichens, lower 6cm of lichens (including "slime area"),4cm humus(or A_0 horizon, zone of fermentation and humus layers),6cm organic-mineral soil (A_2 horizon), and mineral soil (B horizon) at 3dm below the soil surface. Soil horizons follow the descriptions of Lyon, Buckman and Brady(1952). Unfortunately, the mineral soil samples obtained during February 1970 were lost in airline transit.

Samples were individually dried, milled and mixed before aliquots were processed according to standard procedures to obtain standard dry weights. A 500ml standardized container of the dried material was analyzed for gamma-emitters in a well-type 9 x 11 inch NaI (Tl) crystal connected to a 256-channel analyzer. Gamma-ray energy spectra were converted to estimates of radionuclide concentrations through a computer-programmed set of correction constants. Samples were then ashed at 600°C to reduce them to white ash or mineral constituents and then processed by fuming nitric acid chemical separation to isolate ^{90}Sr as $^{90}SrCO_3$. The samples were stored until ^{90}Sr-^{90}Y secular

equilibrium was achieved and the ^{90}Y was extracted by TTA and counted on a low-background beta counter.

RESULTS

Lichen biomass and species composition at the two Anaktuvuk Pass locations (Table 1) were slightly different, although only 200m apart. These differences were considered insignificant for the purposes of this report, even though species differences in radionuclide concentrations have been observed (Hanson, Watson and Perkins 1967).

Concentrations of ^{90}Sr and ^{137}Cs in lichens during the period 1962 - 1970 showed strong correlation with fallout deposition (Figure 2), but with a rather steady increase to a period of maximum values during 1965-1966. Superimposed upon this long-term trend was a seasonal cycle that appeared to yield maximum values in late summer and minima during mid-winter. This contrasted with reports of tenacious binding of fallout radionuclides, especially ^{137}Cs, in the mycellia of lichens (Nevstrueva et al., op. cit.) and the long half-times previously discussed. Our own experiments have included artificial amounts of ^{134}Cs and ^{137}Cs applied to natural lichen communities in single drops to individual podetia and sprinkled in simulated rain over $25m^2$ plots. Although fallout could not be precisely simulated by the experiment, ^{137}Cs droplets applied to single podetia and sampled annually for four years yielded a biological half-time of 6.7 years. However, the results from the ^{134}Cs sprinkled on lichens and wetted by a heavy rain immediately following application showed no decrease after four years (Table 2).

Concentrations of potassium-40, manganese-54, zinc-65, ruthenium-106,

and cerium-144-praseodymium-144 in lichens during the intensive sampling period 1964-1968 showed individualistic behavior in their cycling properties. The non-selectivity of lichens for ^{65}Zn and ^{106}Ru resulted in their rapid loss from the communities.

Stratified samples of lichens and substrate collected during summer and winter months further demonstrated the individual and seasonal differences in radionuclide cycling properties (Figure 3). Lowest retention occurred for ^{65}Zn and ^{106}Ru, which moved fairly rapidly through the lichens and down into the A_2 and B soil horizons. Manganese-54 concentrations was slightly higher in lichen tops than in lower portions, and in February appeared to move from the lower strata upward into the lower portion of the lichens. Cerium-144 - praseodymium-144 occurred as a nearly uniform label throughout the strata, and moved deep into the soil. Natural ^{40}K concentration in soil horizons was 7-10 times greater than in lichens and was greater in humus than in lichens during winter months. Exchange of ^{90}Sr between humus and the lower portion of lichen was indicated by seasonal shifts of concentrations. Soil beneath the lichens contained barely detectable amounts of ^{90}Sr, and negligibly higher concentrations in the A_2 horizon compared to B horizon may have resulted from the small amount of vascular plant roots contained therein.

Cesium-137 concentrations were relatively stable in the upper 6cm of lichens, showed an apparent cycling between lower portions and the humus layer, and moved more readily into soil horizons than did ^{90}Sr. The seasonal change in vertical distribution of ^{90}Sr and ^{137}Cs in terms of total amount of radionuclide contained within the biomass of one square meter was substantial

(Table 3). Total and specific amounts of both radionuclides increased in the lower 6cm portion of lichens during the winter period, apparently at the expense of amounts both above and below that stratum.

DISCUSSION

The observations of most studies of radionuclide retention capacity of lichens have been principally based upon samples obtained during summer months (Lidén and Gustafsson op. cit.; Svenson 1967; Hanson, Watson and Perkins op. cit.). Examination of several seasonal measurements contained in these studies suggests, however, that cycling of ^{137}Cs in lichens and mosses in most circumpolar areas is a distinct possibility. Further, the recent lichen experiments of Tuominen (1967 and 1968) are particularly applicable to the observations in natural lichen communities. His results indicated that translocation of cesium and strontium along the Cladonia alpestris thallus was primarily diffusive in character but complicated by cation exchange, especially with respect to Sr ions. This attraction of Sr to the thallus strongly retarded its movement and Cs was, therefore, the more mobile of the two ions. Hale (1967) also reported that arctic lichens were especially prone to absorb strontium. These findings contradict previous opinions that Cs was the more tenaciously held ion, based upon consistent observations of higher ^{137}Cs concentrations in the top portions of lichens that exceeded those of ^{90}Sr by powers greater than the 1.9 ratio of Cs:Sr in radioactive fallout. Part of the explanation in the natural situation may lie in the more rapid translocation of ^{137}Cs from the A_o horizon reservoir and the concept of "reflection at a boundary" as back-diffusion begins from the lichen tops (Tuominen 1968).

Increased concentrations of ^{90}Sr, ^{137}Cs and other fallout radionuclides in lichens, particularly the lower portion, collected in the February-August period of several years is interpreted as upward transport of ions during the increased photosynthetic rate of lichens during winter (Hale op. cit.). Tuominen (op. cit.) suggested that ^{90}Sr transport, at least, was essentially a process of physical chemistry without any indications of metabolic activity, and that ionic movement might be depicted as a pumping action subject to influence of wind, humidity and water content of the lichens. The decreasing values for the biological half-time (λ) of ^{137}Cs droplets in Table 2 may represent the gradual diffusion of the original ^{137}Cs application from the podetia subjects into the humus layer. The apparent immobility (λ= 51.3 years) during the first year of observation might be due to several factors, such as adsorption to external mycellia, adjustment of the $^{137}CsNO_3$ (pH 4.0) by the podetia, or rather strict containment of the innoculate within the ten podetia randomly sampled. Sampling error was considered minimal in light of coefficients of variation that ranged from 0.08 to 0.18, which was less than that observed in several natural lichen samples obtained from northern Alaska (Eberhardt 1964). Similar studies of ^{90}Sr droplets on lichen podetia yielded biological half-times of 1.0 to 1.6 years, with the longer period observed during the first year after application, and coefficients of variation of 0.20 to 0.87. These results seem compatible with the translocation studies cited previously and it is proposed that the apparently longer half-time of ^{137}Cs compared to ^{90}Sr in lichens is due to more rapid and freer movement of that radionuclide and that a lower fraction of the total inventory is tightly bound within the A_o horizon. Strontium movement is viewed as slower, more complicated by ion exchange and other

processes, and once in the A_o horizon tends to be tightly bound there and unavailable for relocation into the lichen podetia.

It is concluded that radionuclide cycling within natural arctic lichen communities is a more dynamic mechanism than previously noted, that it is compatible with several studies of northern lichen communities, and that it at least partially accounts for the spring pulse of ^{137}Cs body burdens of northern Alaskan caribou observed annually. Further refinement of transfer rate constants await controlled experiments within the natural community compartments.

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Table 1. Lichen biomass and species composition of study plots, Anaktuvuk Pass.

Species	Per cent composition by weight: Control Plot	Alternate Plot
Cladonia rangiferina	48.0	48.0
" alpestris	46.0	39.4
" mitis	0.1	5.5
Alectoria ochroleuca	2.1	3.5
Cetraria cuculata	2.4	2.1
" islandica	0.6	0.6
" richardsonii	0.2	0.2
Thamnolia vermicularis	0.6	0.5
Dactylina arctica	0.2	0.1
Totals	100.0	100.0
Community biomass:		
Standard dry kg/m^2 $\pm$ S.E.	1.41 $\pm$ 0.03	1.87 $\pm$ 0.08
N	61	34

Table 2. Retention of ^{134}Cs and ^{137}Cs by natural lichens at Anaktuvuk Pass. Single drops of ^{137}Cs were applied to individual podeita and ^{134}Cs was sprinkled on 25 m^2 lichen carpets.

Days after application	Sprinkled Treatment nCi ^{134}Cs per m^2	Single Droplet Treatment nCi ^{137}Cs per podetium		λ
1	971 ± 47	1	22.1 ± 0.56	
23	990 ± 89			
63	967 ± 45			
380	823 ± 34	370	21.8 ± 0.75	51.3y
752	905 ± 53	736	19.1 ± 1.08	9.0
1173	890 ± 44	1068	16.9 ± 0.81	7.6
1505	1020 ± 142	1465	14.6 ± 0.82	6.7y

Table 3. Total amounts of ^{90}Sr and ^{137}Cs in vertical strata of Cladonia lichen communities during summer and winter periods.

Stratum	Biomass (kg per m^2)		Radionuclide content (nCi/m^2)			
			Strontium-90		Cesium-137	
	July 1969	Feb. 1970	July 1969	Feb. 1970	July 1969	Feb. 1970
Top 6 cm lichens	1.30	0.80	6.2	5.7	34.2	19.2
Lower 6 cm lichens	1.64	1.79	3.6	7.6	10.4	17.0
A_o	2.38	2.40	2.9	1.2	2.7	1.4
A_2	6.83	6.80	0.7	0.4	1.6	1.0

Figure 1. Map of northern Alaska showing sampling sites. Intensive studies were done at Anaktuvuk Pass, semi-annual samples were collected on caribou winter ranges along southern edge of the Brooks Range.

Figure 2. Strontium-90 and cesium-137 concentrations in lichens at Anaktuvuk Pass in relation to fallout deposition rates measured at Fairbanks, Alaska during the period 1962-1970.

Figure 3. Radionuclide concentrations in vertical strata of an Anaktuvuk Pass Cladonia lichen community during summer and winter periods. Abbreviations are: T= Top 6 cm of lichens; L= Lower 6 cm of lichens; A_o, A_2 and B = respective soil horizons.