The Chernobyl accident: Can lichens be used to characterize a radiocesium contaminated range?

Tsjernobyl-ulykken: Kan lav nyttes til karakterisering av et radioaktivt forurenset reinbeite?

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Summary: Many of the lichen species that are important in the lichen dominated plant communities in the Norwegian mountains are important reindeer winter forage. They are also organisms that collect fall-out from the atmosphere. The Chernobyl accident brought, among other, radioactive Cesium, and from lichens this follow the food chain to reindeer and finally man. From region to region this fall-out was unevenly distributed and methods are needed to compare winter ranges and to monitor the developement of radioactive levels in the lichen carpet.

Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis, Cladina mitis, C. stellaris and *Stereocaulon paschale* was collected in the Dovre mountains to compare species levels and to study collection methods. We found that from spot to spot there is a very large variation between samples, even within the same species. Because of this we are not able to show significant species differences. We found, however, that species from more or less snow free ridgetops, *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis* and *Cladina mitis* showed less variation and thus must be recommended as the best species for monitoring and comparison of ranges.

Rangifer, 7(2): 46–50

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Sammendrag: Mange av de lavarter som er viktige i lavdominerte plantesamfunn i de norske fjell er viktige som vinterfôr for rein. Disse organismer samler også nedfall fra atmosfæren. Ulykken i Tsjernobyl brakte, blant annet, radioaktivt cesium, og fra lav følger dette næringskjeden til rein og endelig mennesket. Fra område til område var dette nedfallet ujevnt fordelt, og det kreves metoder for å sammenligne vinterområder og for å overvåke utviklingen av det radioaktive nivå i lavmattene. *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis, Cladina mitis, C. stellaris* og *Stereocaulon paschale* ble samlet på Dovrefjell for å sammenligne artsnivåene og for å studere innsamlings-prosedyrer. Vi fant at det fra sted til sted var en svært stor variasjon, til og med innen samme art. På grunn av dette var vi ikke i stand til å vise statistisk sikre forskjeller mellom artene. Men vi fant at arter fra mer eller mindre snøfrie rabbetopper, *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis* og *Cladina mitis* viste mindre variasjon og derfor må anbefales som de beste arter for overvåkning og sammenligning av områder.

Rangifer, 7(2): 46–50

A large proportion of the Norwegian land area is alpine tundra. This, besides being attractive scenery, is utilized by grazing animals, mainly sheep and reindeer. Of the latter about 186 000, north of Trondheim, are herded by laps; south of this there are about 11 000 domestic and 40 000 wild reindeer. After the Chernobyl accident, reindeer meat from most wild reindeer areas and the southern third of the tame reindeer area contained high levels, >6000 Bq/kg meat, of radiocesium. In some areas levels exceeded 10 000 Bq/kg (Skogland 1987a and b).

This means that about 2 500 reindeer owners (Saami) and 23 000 hunters may face a disaster: no one wants to eat the meat they harvest.

Variation in radiocesium consentrations in reindeer from different ranges is thought to relate to «hot spot» areas in Scandinavia caused by uneven distribution of rainfall in the period 28. April to 5. May 1986 (Saltbones 1986). In addition, a large area received dry fallout, but this was less contaminated.

Hvinden and Lillegraven (1961) first drew attention to risk of contamination with radioactive Cesium and Strontium passed along a food chain from lichens to reindeer to man. Lichen collect and store radionuclids in the ecosystem. These organisms absorb water through their whole surface, and store the dissolved mineral ions with great efficiency (Tuominen and Jaakkola 1973, Kershaw 1985, Ellis 1987). They do this mainly by strongfield ionic exchange in the fungal cell wall, and not by incorporating them as part of the living cell as plants with roots do. In addition it is important to note that particles in non-ionic form also will be sucked into the thallus, provided they are small enough, 1 – 2 μm. Different species of lichens may differ in this respect.

Knowledge about accumulation and retention of Cesium in the alpine ecosystem is badly needed, and a radioecological research program was started in May 1986. We need methods to compare the burden of contamination in different winter ranges. Forage lichen have been collected for this before appropriate sampling procedures were developed. Results reported here show how sampling may be done to minimize uncertainty due to stochastic and systematic variation.

Methods

We have two set of samples taken to study the variation in radiocesium content between and within species from different habitats. The first comes from lichens put out originally for growing experiments (Gaare 1986a). We have two study sites: one in the western part of the Dovre mountain range at 62°22,5' n.l., 8°33' e.l., the Aursjø growth field, and another further east on the Dovre plateau proper at 62°16' n.l., 9°36' e.l., the Grønbakken growth field. The western site has 800 mm of precipitation per annum, the eastern site has 400 mm. The difference falls mainly as snow in the winter period.

The lichens were set out in 1979 in perforated plastic trays placed tight together covering 1.7 sq.m under what is considered equal environmental conditions. Two species is studied viz. *Cladina stellaris* and *Cetraria nivalis,* in 8 to 9 replicates from each site. The plants were taken in for measurement of radioactivity in October, 1986.

The second set of samples were collected in September 1987, from a location 200 m from the eastern study field. We sampled the following species, listed according to their increasing requirement for snow protection: *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis, Cladina mitis, C. stellaris* and *Stereocaulon paschale.* One sample consisted of 10–15 subsamples picked from an area of 1 ha (10000 sq.m). This is a sampling procedure practiced in connection with comparison of reindeer winter pastures. We took 5 replicate samples for each species so that a variance and standard deviation could be calculated.

In the laboratory the samples were sorted and the lichen thalli was divided in an upper living part and a lower rotting part. Samples were dryed and weighed at 70°C before they were sent to The Norwegian Technical University where radioactivity was measured with a Canberra multi-channel reading system with a GeLi-detector. Only the readings of the living part are shown here. Results for Cs-134 and Cs-137 have been combined.

Results and discussion

The consentration of Cs-134 and Cs 137 in lichens in the Dovre mountains, Norway increases with altitude and with increasing wind exposure (Gaare 1986b). Species growing on the ridgetop viza. *Alectoria ochroleuca* and *Cetraria nivalis,* showed larger values than those dominating the lee sides, e.g. *Cladina mitis, C. stellaris* and *Stereocaulon paschale.*

In contrast to fallout from nuclear bomb tests, the fallout from the Chernobyl accident varied considerably not only from contry to contry, but also over very short distances – a meter or so. Paired samples of *Cetraria nivalis* collected less the 1 m apart in the Dovre mountains in August 1986, for example, ranged from 4700 to 18200 Bq/kg. The range in similarly paired samples of *Cladina stellaris* was from 6900 and 66000 Bq/kg. At first we suspected a specific variation in the absorption of Cesium, but the species we studied had small, but important differences in their habitat ecology. *Alectoria ochroleuca* and *Cetraria nivalis* dominate the top of ridges that have nil or very shallow snow cover in winter. *Cladina* species dominates on slightly more protected places, and *Stereocaulon* often covers depressions which may become flooded in the thaw in spring. There may also be differences in moisture regimes in the snow free months. Ridgetops lichens dry out much earlier than those growing in depressions. Small topographic irregularities is all that is needed to create large differences in moist periods for poikilohydric organisms like lichens or mosses.

So far it seemed that variation of radioactivity might have been due to habitat rather than species differences. I concluded that the physical reason for differences in the radiocesium content in these lichens was mostly due to a different moisture content at the time when the fallout from Chernobyl came. A dry sponge may absorb more water and contamination than a wet one. And lichens (and many mosses) work very much like sponges in this respect.

Lichens with the highest consentrations of radionuclids came from habitats judged to be the dryest. The main differences which I observed are thus partly explained by the sponge hypothezis. However, there are exceptions and there must be other sources of variation besides conditions on the ground.

Table 1 shows radiocesium content of *Cetraria nivalis* and *Cladina stellaris* grown under near identical environmental conditions from each of the two experimental sites Grønbakken in the east and Aursjø in the west. We see that even in samples of lichens of the same species from the same 1.7 sq.m the variation have a standard deviation of 64 and 83 percent of the mean (100 * coefficient of variation) at the Grønbakken site and 18 and 39 at the Aursjø site. Based on a simple t-test (Tab 1 B) between pairs of species and sites no significant differences exist among these samples, the number of samples is too small. Meat from reindeers harvested in the western part of the range, near the Aursjø growth field, shows significantly lower values than those from Grønbakken (Skogland 1987a).

The sampling undertaken to study variation between species is shown in table 2. Each sample was made up of 10 to 15 subsamples picked

Table 1. A. Radiocesium content (Cs-134 plus Cs-137) of lichens: Identical conditions. Samples grown under identical environmental conditions at the Aursjø (W) and Grønbakkien (E) growth field. Readings in Bq/kg dry weight of the upper 3 cm (living part) of the thallus.

Tabell 1. A. Innholdet av radiocesium (Cs-134 pluss Cs-137) i lav: Identiske forhold. Prøver vokst under identiske miljøforhold ved Aursjø (W) og Grønbakken (E) vekstfelter. Avlesningene er i Bq/kg tørrvekt av de øvre 3 cm (levende del) av lavskrotten.

Species *Art*		n *n*	Mean *Snitt*	St.dev. *St.avv.*	100*c *100*c*
Cetraria nivalis	East	9	20400	17000	83
Cetraria nivalis	West	9	14500	5700	39
Cladina stellaris	East	9	12500	8100	64
Cladina stellaris	West	9	14800	2700	18

n = number of samples, c = coefficient of variation (st.d./mean)
n = antall prøver, c = variasjonskoeffisienten (st.avv./snitt)

Table 1. B. t-values and degrees of freedom
Tabell 1. B. t-verdier og frihetsgrader

		Cet.niv. E	*Cet.niv.* W	*Cl.st.* E	*Cl.st.* W
Cetraria nivalis	East		16	16	15
Cetraria nivalis	West	0.98		16	15
Cladina stellaris	East	1.25	0.02		15
Cladina stellaris	West	0.92	0.11	0.75	

from an area 100 by 100 m. This procedure is obviously not very good. A t-test between pairs of species (Tab 2 B) shows no differences on the 5% level. The standard deviation is large, about 30 percent of the mean for species growing on the ridge, *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis* and *Cladina mitis,* and about 80 percent for species requiring snow protection, *Cladina mitis* and *Stereocaulon paschale.*

Weather conditions may explain this. When contaminated rain fell on 28. April, 1986 the mountains were partly snow covered. According to information from a nearby meteorological observation site, it is very likely that the former species was snow free whereas the latter two was partly covered. This would add to the heterogenous dryness thought to explain the uneven distritubion of contamination shown for non covered species (Gaare 1986b and 1987).

Data from Table 1 appear to contradict this. The coefficient of variation in samples from the eastern site is larger than in samples from the western one. But there experimental field in the west was covered by snow, while the eastern one was snow-free. There it might, therefore, have been differences in thallus moisture due to minor variations in wind and sun exposure. Details known about the weather in April 1986, prior to the accident, support this (Gaare 1987).

From the analyses we have done, we conclude that lichens growing on the ground may be used to compare the load of radiocesium on ranges from the Chernobyl accident. The best results is to be expected if one uses species growing on ridgetops avoiding prolonged snowcower, viz. *Cornicularia divergens, Alectoria ochroleuca, Cetraria nivalis, Cladina mitis. Cladina stellaris* and *Stereocaulon paschale* are less suitable. In order to obtain reliable results, the sample must be composed of not less than 10 – 15, preferably more, subsamples picked from a large area. It is doubtful whether this is precise enough to allow determin biological halflives of radioactive contamination in the species we study.

Table 2. A. Radiocesium content (Cs-134 plus Cs-137) of lichens: Parallel sampling. Parallel sampling of species near Grønbakken growth field. Readings in Bq/kg dry weight of the upper 3 cm (living part) of the thallus.

Tabell 2. A. Innholdet av radiocesium (Cs-134 pluss Cs-137) i lav: Parallell innsamling. Parallell innsamling av arter nær Grønbakken vekstfelt. Avlesningene er i Bq/kg tørrvekt av de øvre 3 cm (levende del) av lavskrotten.

Species *Art*	n *n*	Mean *Snitt*	St.dev. *St.avv.*	100*c *100*c*
Alectoria ochroleuca	5	18300	5600	31
Cetraria nivalis	5	20200	5500	27
Cladina mitis	5	11200	3500	32
Cladina stellaris	3	7600	6500	85
Cornicularia divergens	4	20800	6600	32
Stereocaulon paschale	5	19700	14700	75

n = number of samples, c = coefficient of variation (st.d./mean)
n = antall prøver, c = variasjonskoeffisienten (st.avv./snitt)

Table 2. B. t-values and degrees of freedom
Tabell 2. B. t-verdier og frihetsgrader

	Al.och.	*Cet.niv.*	*Cl.mit.*	*Cl.st.*	*Co.div.*	*St.pas.*
Alectoria ochroleuca		8	8	6	7	8
Cetraria nivalis	0.56		8	6	7	8
Cladina mitis	2.40	3.10		6	7	8
Cladina stellaris	2.46	2.95	1.02		5	6
Cornicularia divergens	0.62	0.14	2.83	2.63		7
Stereocaulon paschale	0.20	0.07	1.26	1.31	0.13	

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