Chernobyl cesium in the Swedish moose population: Effect of age, diet and habitat selection

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Dissertation 1994

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ABSTRACT

In spring 1986 a breakdown of a nuclear reactor occurred in Chernobyl in the former Soviet Union. Radioactive material from this accident was carried by winds over much of Europe, including Sweden where some of it was deposited (mostly by rain). For radioecological studies the most important isotope deposited was ^{137}Cs because it was a major component of the fall-out and long lived (30.2 year half-life). In Sweden many products from the forest (i.e. game and berries) are commonly used in households, so ^{137}Cs deposition in the forest could therefore be a important path for ^{137}Cs to the human population. The most important game in Sweden is moose (*Alces alces* (L.)). To study the ^{137}Cs levels in moose, hunters were asked to send in moose meat for analysis. About 6500 samples were analysed from 1986-1993.

As expected, there was a positive correlation between the fall-out of cesium from Chernobyl and the cesium concentration in moose. There were also age-dependent differences in ^{137}Cs concentration between moose calves and adults, with calves tending to have higher levels than adults. Some differences also existed between the sexes although they were less pronounced (females had a higher ^{137}Cs concentration than males).

The differences in ^{137}Cs concentration between moose of the same age and sex, results from individual moose consuming plants of different ^{137}Cs concentrations, due to the use of different habitat types. The differences in ^{137}Cs levels between years probably depends on between-year variation in habitat utilization due to the weather. During warm summers and autumns, moose utilize more wetlands (cool habitats during warm days) or mature forests (which are shady during sunny days) and consume the plants (of high ^{137}Cs levels) found there, whereby their meat will have a higher ^{137}Cs concentration. If, during colder summers, moose instead use farmlands or clear-cuts forest areas and consume the plants (of low ^{137}Cs) found there, a lower ^{137}Cs concentration will be the case.

The ^{137}Cs concentration in moose also fluctuates seasonally depending on diet, i.e. there are high average concentrations and large difference between individual moose killed during the plant growing season, but low ^{137}Cs concentrations and low variation between individuals and years, for moose killed during the winter.

The analyses of ^{137}Cs in moose and its food plants from before and after the Chernobyl accident indicates that the ^{137}Cs from Chernobyl will stay in the northern forest ecosystem for a long time. The physical decay (30.2 years) seems to be the major factor for its disappearance from the ecosystem. I also expect that the fluctuation between years in the ^{137}Cs concentration will persist, although decrease in maximum values.

Key words: ^{137}Cs, cesium, radioecology, moose, age, diet, habitat selection

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Chernobyl cesium in the Swedish moose population: Effects of age, diet and habitat selection

Chernobyl cesium in the Swedish moose population: Effects of age, diet and habitat selection

List of Papers

This thesis is a summary of the following papers which will be referred to by their Roman numerals.

I. Danell, K., P. Nelin and G. Wickman 1989. ^{137}Caesium in northern Swedish moose: The first year after the Chernobyl accident. AMBIO 18:108-111

II. Palo, R.T., P. Nelin, T. Nylén and G. Wickman. 1991. Radiocesium levels in Swedish moose in relation to deposition, diet and age. Journal of Environmental Quality 20:690-695

III. Nelin, P. and T. Nylén. 1994. Factors influencing the changes over time in ^{137}Cs levels in boreal-forest plants in Sweden. Science of the Total Environment (in press)

IV. Nelin, P. 1995. Radiocaesium uptake in moose in relation to home-range and habitat composition. Journal of Environmental Radioactivity 26:(in press)

V. Nelin, P. Influence of weather on the uptake of radioactive cesium by moose (submitted)

Chernobyl cesium in the Swedish moose population: Effects of age, diet and habitat selection

-THESIS-

INTRODUCTION

The fall-out of ^{137}Cs over Sweden

In spring 1986 a nuclear reactor break-down occurred at the power station of Chernobyl, in the former Soviet Union. The prevailing winds brought a considerable part of the released radioactivity to Sweden. About $4.25*10^{15}$Bq of ^{137}Cs was deposited over Sweden (mostly as wet deposition) corresponding to about 5% of the total amount of released radiocesium from the Chernobyl accident (Persson et al. 1987, Edvarsson 1991). The part of Sweden that received most of this deposition was the north-east coastal areas from Gävle up to Skellefteå and parts of the northern inland (Fig. 1). The pre-Chernobyl deposition of ^{137}Cs in this area originated from atmospheric testing of nuclear bombs during the 50's and 60's when about 3000 Bq/m^2 (in total $1.25*10^{15}$Bq over Sweden) was evenly distributed over Sweden (Edvarsson 1991).

The contamination from Chernobyl of the forest ecosystem in this area made people concerned about the situation in fish, game and wild berries. A high ^{137}Cs concentration in the semi-domestic reindeer (*Rangifer tarandus* L.) was expected from earlier studies (Lidén and Gustafsson 1967, Hanson 1985), but information about moose (*Alces alces* (L).) was almost non-existent and the ^{137}Cs levels during the moose hunting season could only be speculated. This lack of knowledge was unsatisfactory because in Sweden meat from game is a considerable contribution to many households,

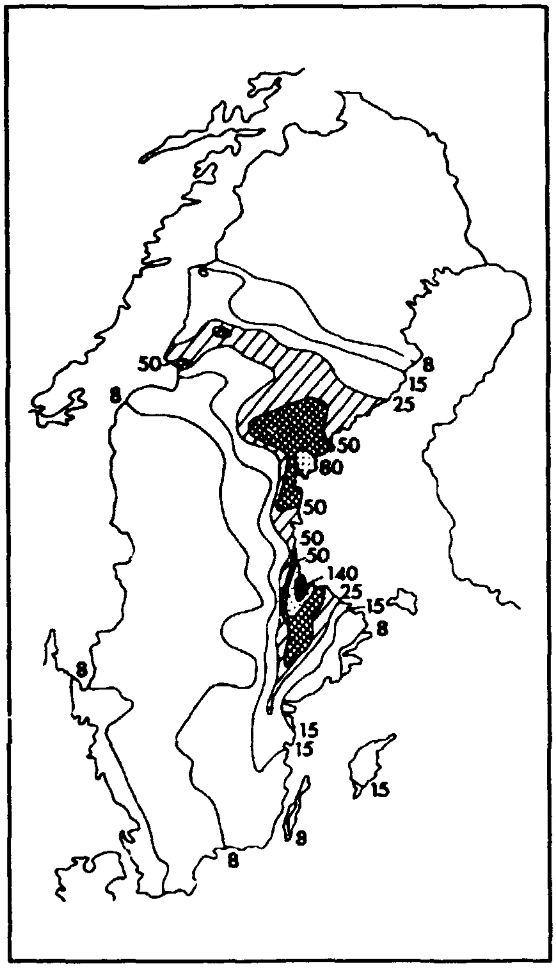


Figure. 1 Deposition map of Sweden in kBq/m² ^{137}Cs (after Persson et al. (1987), and corrected by Edvardson (1991).

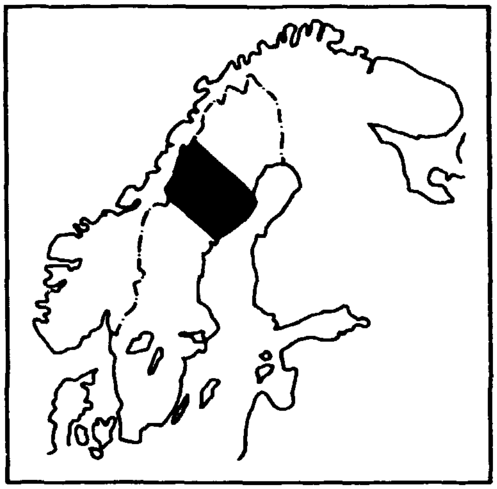


Figure. 2 The sampling area in northern Sweden for ^{137}Cs analyses of moose during 1986-93. The area includes Västerbotten and a minor part of Västernorrland.

and moose is the most important game meat (contributing with 14.2 *10^6 kg meat to 237 000 hunters in 1986; Mattson 1990). Moose meat could therefore be an important path for the radiocesium from the forest ecosystem to man. In autumn 1986 (the first moose hunt after the fall-out), the mean cesium concentration in adult moose shot in the Västerbotten and the bordering part of Västernorrland administrative districts (Fig. 2) was 307 Bq/kg meat (406 Bq/kg for calves, Paper I). Because the highest concentration allowed in food for sale in Sweden in 1986 was 300 Bq/kg (later raised to 1500 Bq/kg in meat from fish and game), this concerned many of the hunters enough to stop hunting and discard the moose meat as human food (Paper I). These high levels in moose accentuate the necessity to improve our knowledge of how ^{137}Cs acts in the northern forest ecosystem.

The moose

The moose is the largest existing cervid, with a total length up to 290 cm, shoulder height of 220 cm and a body mass of up to 800 kg for bulls. It occurs in northern forest ecosystems as 7 subspecies (Bjärvall and Ullström 1990).

The moose is a browsing ruminant herbivore which includes mostly twigs and leaves from dwarf shrubs and trees in its diet (Cederlund et al. 1980). The moose changes not only the plant species it utilizes with season, but also the amount of food. The highest intake is during the summer (about 11 kg/day dry mass intake) and the lowest during winter (4 kg/day, Schwartz et al. 1987). The calves born in the end of May weigh over 10 kg and are increasing at a rate over one kg/day until autumn (Markgren 1966). The moose is usually solitary but during snowy winters can aggregate and follow other moose tracks in order to reduce energy costs.

The Swedish moose population grew dramatically during the period 1950 to 1980. Only 30,000 animals were killed in 1960 but about 170,000 were animals killed during 1980 making it the most important game in Sweden.

The radioecology of ^{137}Cs

Plants

The ^{137}Cs concentration in plants is correlated with the ^{137}Cs in the soil (Scheppard and Evenden 1988). This correlation can, however, be influenced by soil type and mineral concentration (i.e. clay binds ^{137}Cs, and potassium can depress ^{137}Cs uptake by plants; Davis 1963, Bakunov 1989). The ^{137}Cs can also be absorbed directly by the foliage of the plant during deposition and then recycled (Bunzl and Kracke 1989). Most of the old studies of the ^{137}Cs-plant relation are done in agricultural systems (Shultz and Klement 1963). However, there are also some studies of natural ecosystems showing that ^{137}Cs uptake by plants growing under natural conditions varies considerably among species, for example cryptogametic plants generally have higher cesium concentration than phanerogams (Gorham 1959). There is also differences in uptake among plants of the same species when growing under different environmental conditions (Davis 1963, Bunzl and Kracke 1986). Plants grown in farmland have lower ^{137}Cs levels than plants growing in forest (Howard et al. 1991). But, it seems that the relative relation, in ^{137}Cs levels, among specific species will be the same in different habitat types although the transfer from soil to plant may vary among sites (McGee et al. 1993).

Animals

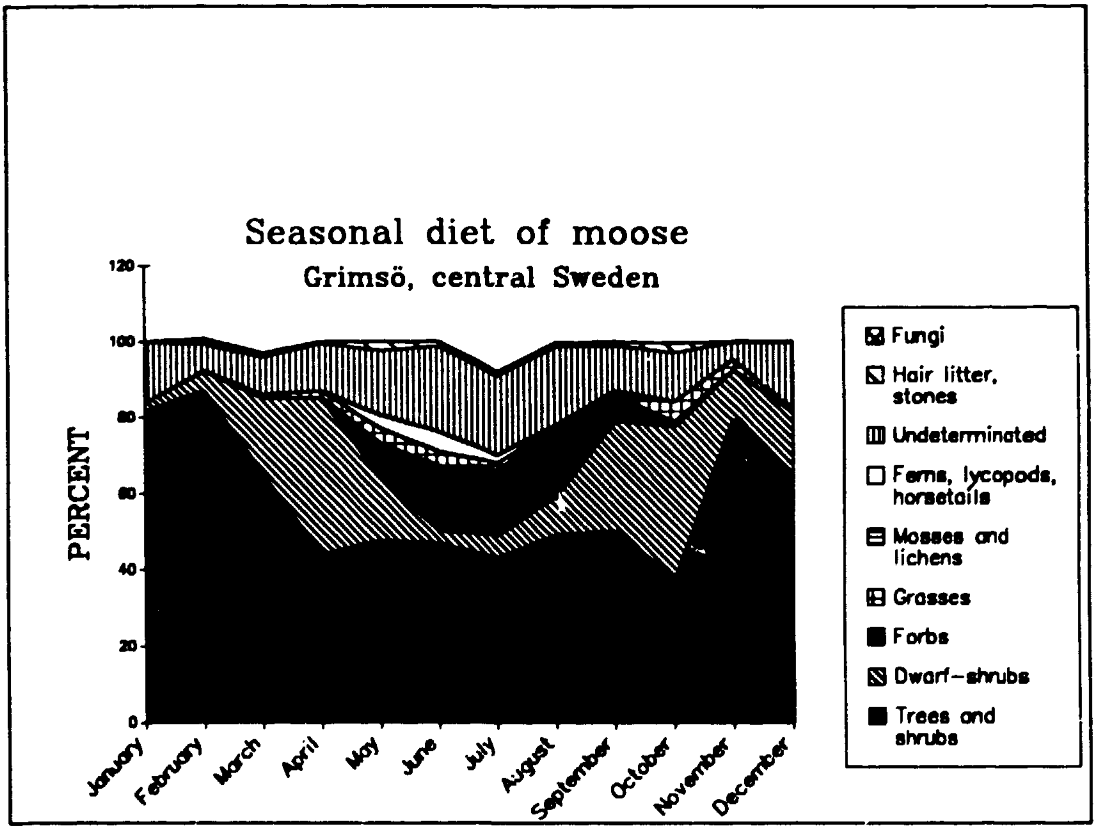
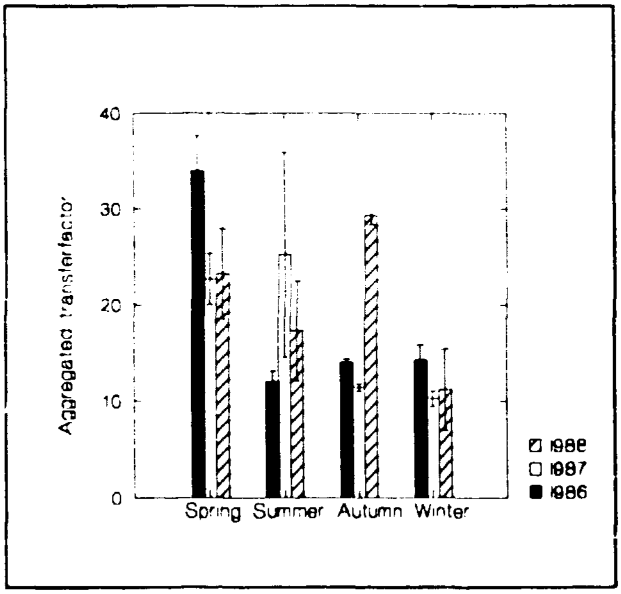


Figure. 3 Seasonal variation in plant diet of moose from central Sweden (after Cederlund 1980)

The levels of ^{137}Cs in herbivores will be influenced by the ^{137}Cs concentration in the plants they eat. The ^{137}Cs concentration in plants tends to be lower than in the herbivores feeding on them, and the ^{137}Cs concentration is even higher in predators (Davis 1963, Kitching et al. 1975, Howard et al. 1991). There will, however, be large differences in ^{137}Cs concentration in the herbivore food between seasons depending on diet selection (Liden and Gustafsson 1967). In the boreal forest most animals exhibit a large seasonal change in diet: during winter many plants that are used by herbivores during summer are unavailable, dwarf shrubs are covered with snow and the herbs are withered. For example, during winter moose diet is dominated by twigs of Scots pine (*Pinus sylvestris)* (but also twigs of other species are included as willow (*Salix* spp.), juniper (*Juniper commu-*



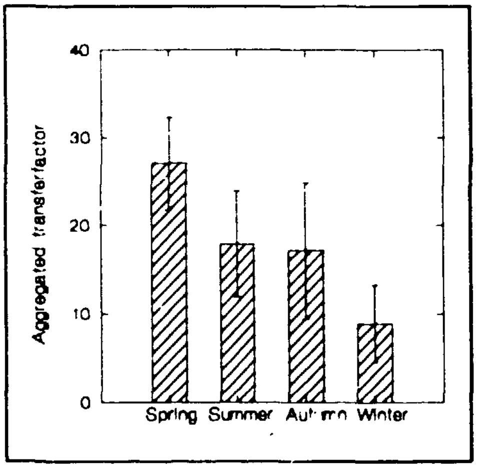


Fig. 4 ^{137}Cs concentration in moose killed during Spring (April 1 - June 15), Summer (June 16- August 31), Autumn (September 1 - November 15) and winter (November 16 - March 31) from 1986 to winter 1988-89 (± standard error).
4a) Shows a year by year comparison of the seasons whereas 4b) shows a comparison season by season with the mean values for each year and season (Fig 4a).

nis) and birch (*Betula* spp.)(Fig. 3. Cederlund et al. 1980, Bergström and Hjeljord 1987). Another cervid in northern Sweden, the reindeer, largely feed on lichens during winter (e.g. Hanson 1985, Åman 1994). Since birches have low ^{137}Cs levels and lichens high levels the reindeer has its highest ^{137}Cs levels during the winter while the moose has its lowest concentration during winter (Fig. 4). From this follow that the two cervide species that occupy the same area will have a different seasonal pattern in the concentration of ^{137}Cs.

Another factor that must be considered in order to understand ^{137}Cs levels in animals is that different species or age classes of the same species, feeding on the same plants, can have different uptake rates of ^{137}Cs, i.e. young, still growing animals, have higher uptake rate than adults (Zach et al. 1989, Howard et al. 1991). However, the trend found within species that smaller mammals have higher ^{137}Cs levels (Zach et al. 1989) has not been observed on the interspecific level (Nelin and Palo 1989).

The ^{137}Cs concentration in mammals depends on the intake and absorption of ^{137}Cs from the food and the biological halflife of ^{137}Cs in the body. The absorption rate of cesium from food ingested by ruminant herbivores (goats, sheep and cows) is normally about 0.6 (Coughtrey and Thorne 1983). The ^{137}Cs in moose does not accumulate over the life of the animal, but is part of daily metabolism and like potassium included in the metabolism. The cesium is distributed throughout all organs and tissues of the body, though the largest amount will be in the muscle tissue (Davis 1963, Bergman et al. 1988, Mayes 1989).

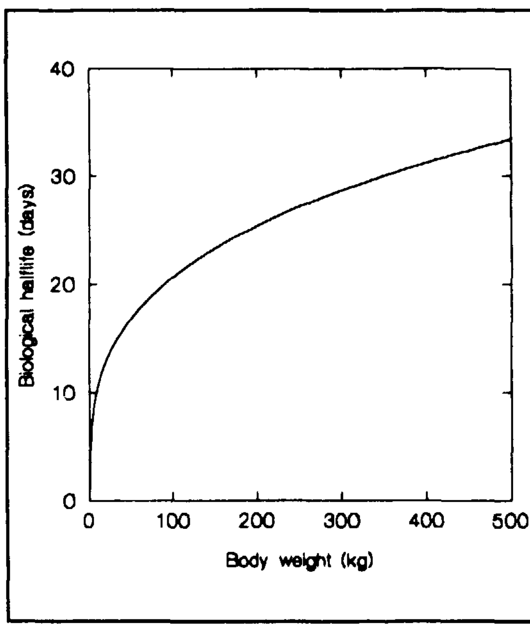


Figure 5. Physiological half life as a function of body weight $T½=5.18*(body\ mass)^{0.3}$

The rate of ^{137}Cs decrease in the animal depends on its size and metabolic rate (Fig. 5). If the animal is fed on cesium-free diet, it will decrease to half the starting value within a fixed period that does not depend on starting concentration (the biological halflife, Davis 1963). Using the formula $T½=5.18*(body\ mass)^{0.3}$ calculated from domestic animals (Fig. 3; Coughtrey and Thorne 1983) the biological halflife for an adult moose (350 kg) would be about 30 days and for the calf in September (130 kg) around 22 days. Therefore the ^{137}Cs concentration in moose depends on the ^{137}Cs concentration in the diet during the last month (Gorham 1959, Bunzl and Kracke 1989, Bothmer et al. 1990). To be able to predict the ^{137}Cs concentration in moose we must know its foraging habits i.e. we must know the ^{137}Cs concentration in the food plants, the composition of food plants in the diet and differences in utilization during the year (Cederlund et al.1980, Renecker and Hudson. 1986, Schwartz et al. 1987).

QUESTIONS ADDRESSED

In the this thesis I will describe the pattern of ^{137}Cs concentrations in the northern Swedish moose population after the fall-out from the Chernobyl accident in spring 1986. I will focus on what influences the present concentrations and make some predictions for the future.

I will address three major questions: (1) What were the ^{137}Cs levels in Swedish moose population after the fall-out from the Chernobyl accident? (2) What affects the ^{137}Cs levels in the moose? (3) How will the ^{137}Cs levels in the Swedish moose population change with time?

MATERIAL AND METHODS

Study area

To address the questions above I used data from two scales. Firs a large regional scale.

where study area was in the middle boreal forest zone of northern Sweden (Ahti et al. 1968; Fig. 2). The ground deposition in the area ranges from below 5,000 to 80,000 Bq/m². The background levels of ^{137}Cs in Sweden 1985, from atmospheric tests of nuclear weapons during the 1950's and 60's, was about 1500 Bq/m² (Edvarsson 1991). The ground deposition after the Chernobyl accident was determined from a map with scale 1:1000,000 made after aircraft measurement (Swedish Geological Company 1986, corrected by Edvarsson 1991; Fig. 1).

For the more local scale I sampled ^{137}Cs in soil and plants, in the Vindeln Experimental Forest (64°16'N, 19°48'E) 60 km NW of Umeå. In this area additional samples where collected for time serie analyses on plants. The fall-out in this area was on average 23 000 Bq/m² (SD. 11 000 Bq/m², see Paper).

Sampling and methods of analyses

Moose

To estimate the ^{137}Cs concentration in the moose population, hunters from the administrative districts of Västerbotten and the border of Västernorrland (Fig. 2) were asked to send in meat from killed animals and analyses of ^{137}Cs in tne muscle tissue were performed. The majority of the animals were killed from the beginning of September until the end of December, but about 100 moose killed outside the hunting season were also included (Fig. 4). In total, muscle tissue from 6500 killed were analysed fresh in 100 ml containers on a NaI-scintillation detector (see Paper I for more details).

Plants

In order to understand the ^{137}Cs levels of moose, analyses of ^{137}Cs levels in plants commonly eaten by moose (Cederlund et al. 1980) were performed. Birch (*Betula pubescens* Ehrh.) leaves, and bilberry (*Vaccinium myrtillus* L.) twigs were collected from 31 sites within the large scale area (Paper III and V; ground deposition ranging from 8,000 to 80,000 Bq/m^2) to determine the correlation between ground deposition and ^{137}Cs levels in plants.

To study the initial and seasonal changes in the ^{137}Cs concentration of bilberry and birch, plants were sampled from 15 June 1986 up to the end of October 1989 on the local scale basis. Bilberry was sampled by taking all green parts on at least 10 spots within a 1-ha area in a mature mesic spruce (*Picea abies* L.) forest at 14-day intervals during the first growing season after the Chernobyl accident (1986) and less frequently during the following years. Birch shoots of the current year (or leaves during the summer) were collected from at least 10 trees ranging from 1.5-2.5 m in height in a young birch forest with the same schedule as for bilberry.

At the Vindeln Experimental Forest ground deposition was determined by soil samples collected with a plastic auger (diam. 12 cm) to a depth of 20 cm in the mineral soil and by *in situ* gamma spectrometry (for more details see Paper III).

All plant and soil materials were dried at 70°C to constant mass and homogenized before analysis. The analysis was formed on a high power germanium detector (55% ortec) or a GeLi detector (32% PTG, for a more detailed information see Paper III).

Most statistical analyses used in this thesis are nonparametric since the data are usually non-normal distributed. The statistical analyses were done with the SYSTAT statistical package (Wilkinson 1988).

RESULTS AND DISCUSSION

<u>^{137}Cs levels in moose and its foods plants</u>

^{137}Cs levels and the fall-out

As expected, a significant correlation existed between ^{137}Cs concentration in moose killed in 1986 and the amount of fall-out at the place it was shot, but the correlation was poor ($n=3000$, $r^2=0.37$, $P<0.001$, Paper I, II, IV and V). There existed up to a tenfold difference in ^{137}Cs levels between moose from areas with the same ground deposition (Paper II, Fig 2). There was also a significant correlation between ground deposition and the ^{137}Cs concentration in both birch (n=30, r^2=0.19, P=0.015) and bilberry (n=31, r^2=0.32, P<0.01) from the regional samples collected on ground deposition ranging from 8 000 to 80 000 Bq/m² although the correlation was low (Paper III, Figs 2 and 3). The ^{137}Cs levels between birch and bilberry were significant both on regional and local scales (Paper III). The lowest concentration for a single plant sample at the Vindeln Experimental Forest was found in fireweed (*Epilobium angustifolium* L.:31 Bq/kg, dry mass) and the highest value was found in a species of water-lily (*Nymphaea candida* L. :48,000Bq/kg). The mean ^{137}Cs concentration 1986 in these two species differed nearly 100 times (for more details see Paper III).

Biological factors influencing the ^{137}Cs level

The ^{137}Cs analyses of moose meat from the hunt in September 1986 showed a clear difference between adults and calves and between sexes (Papers I, II). The difference between adult and calf could depend on both diet and size since the smaller calves respond faster to changes in ^{137}Cs intake than adults. They could therefore differ in ^{137}Cs levels from adults depending on the seasonal change in diet (Peek 1974, Cederlund et al. 1980). The differences between calf and adult vary with time (Fig. 5): the calves reach a high ^{137}Cs level during the summer while the levels in adult are still only slowly increasing after the winter minimum, and the adults may never reach equilibrium before they changes diet and thereby the intake of ^{137}Cs (Figs. 3 and 5). Although size dependent differences in biological halflife exist, the most probable explanation for the ^{137}Cs differences between adults and calf are diet differences and that young animals accumulate ^{137}Cs more readily than older ones (Davis 1963).

The difference between sexes could also be explained by differences in diet since some studies are indicating differences between the cervid sexes in food and habitat choice (Beier 1987, Leptich and Gilbert 1989). If the sexes differ in preference for plant species (like herbs with low ^{137}Cs levels or dwarf-shrubs with high), or if they differ in habitat selection, e.g. one utilizes farmland and clear cut areas (where plants of low ^{137}Cs were found (Paper IV) while the other prefer mature forests and mire (with plants of higher ^{137}Cs concentrations) it would result in a large difference in ^{137}Cs levels between the sexes.

The diet choice for moose has been investigated in many studies (e.g. Jordan et al. 1973, Peek 1974, Belovsky et al. 1978, Cederlund et al. 1980, Schwartz et al. 1987, Bö and Hjeljord 1991, Paper V). These papers describe the moose as a generalist which utilizes different plant species depending on availability and digestibility, but also that a lack of sodium and weather can influence diet selection. By combining this knowledge with a knowledge of the habitat types in the home range, it is possible to predict the ^{137}Cs levels in moose (Papers IV and V).

^{137}Cs concentration changes with time

Short term (first months after the fall-out)

After the fall-out in spring 1986, some moose were killed and muscle samples analysed to check the ^{137}Cs uptake in the moose population of Västerbotten. The ^{137}Cs in these moose killed a few weeks after the fall-out from Chernobyl had a relatively low ^{137}Cs concentration. Later, moose samples showed a peak after about one month to then decreased until early September when the official moose hunt started (Fig. 6). The moose will have their highest ^{137}Cs values after some time lag compared to the food plants because it takes time for the moose to reach a steady state with the ^{137}Cs in their food. During the time it takes for the moose to reach equilibrium with the contaminated plants, the high ^{137}Cs concentrations in the plants already had started to decrease (Figs. 6 and 7). The rate of the decrease from June to August indicated a biological halflife of about 25 days for the adult moose. This is very close to the theoretical halflife (30 days using the formula from Davis 1963), and much faster than might be expected because moose were not on a cesium free diet (Coughtrey and Thorne 1983). This rapid decrease may be the same phenomena as was earlier found in reindeer which have a shorter biological halflife for ^{137}Cs during summer than in winter (Holleman et al. 1971, Åman 1994) In the birch and bilberry samples collected every second week there was a continuous decrease during the first growing season after which the concentrations stabilized with small fluctuations (Fig. 6). This decrease is what would be expected if the plant surface was initially directly or indirectly contaminated by cesium, and then partly was washed off and the remaining cesium later diluted by growth of new plant tissue. After the first surface contamination, most of the ^{137}Cs has been integrated in to the biota or fixed in the soil. The ^{137}Cs concentration in plants has thus reached a steady state when the physical halflife is the governing factor behind the decrease (Bergman et al. 1994).

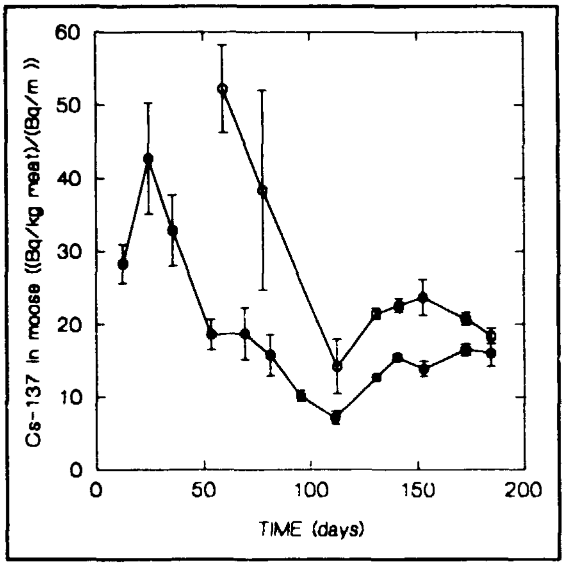


Fig. 6 ^{137}Cs concentration in moose killed the first year after the fall-out in 1986. Filled symbols are adult and open are calves (± standard error).

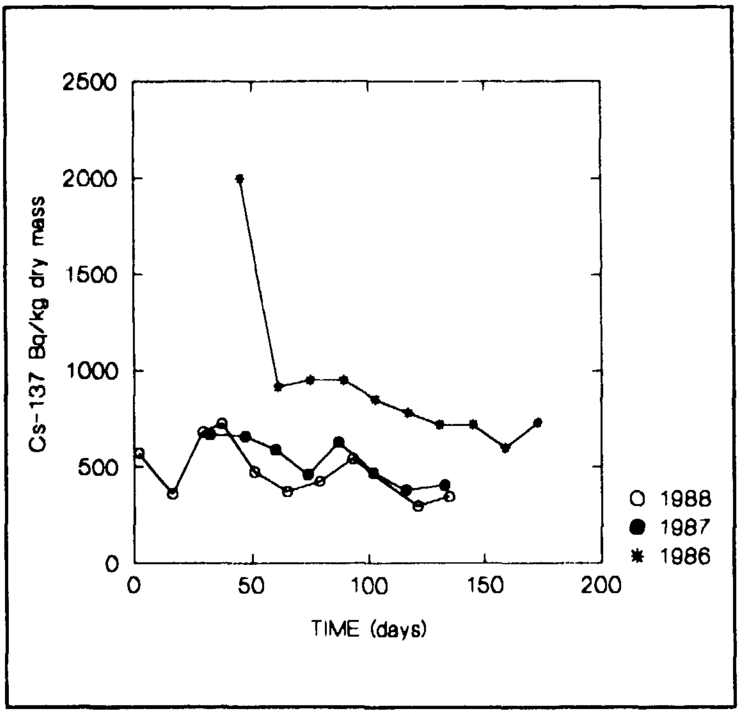


Figure. 7 ^{137}Cs concentration in bilberry twigs during the growing seasons 1986, 1987 and 1988. Samples are composites samples content of ten subsamples from within 1 ha. in a mature spruce forest.

Intermediate time period (first years after the fall-out)

The ^{137}Cs concentration in moose has varied with season after the first year: the concentration decreases during winter and increases during summer (Fig. 4). The ^{137}Cs in moose depends on two factors: the ^{137}Cs level in its food plants and the uptake of ^{137}Cs from it (Mayes 1989). In this thesis I have concentrated on the ^{137}Cs in the food. The moose adjust food intake in response to availability and quality in different seasons (Cederlund et al. 1980, Renecker and Hudson 1986) so the ^{137}Cs concentration in the moose will also fluctuate.

The ^{137}Cs levels in plants decreased the first year and have then fluctuated around a lower level (Paper III). There is, however, still large variation between the plant species, and it also seems that the difference in ^{137}Cs concentration between habitat, but within species, increases with time (Paper IV).

The large variation between years in ^{137}Cs levels for moose shot during the hunt has been one of the most discussed phenomena by hunters and scientists concerning the ^{137}Cs in moose (e.g. Johanson and Bergström 1989, Bothmer et al. 1990, Paper II, V). This between-year variation is most pronounced during early September. Comparing the seasonal cesium levels over years the fluctuation during the winter seems to be lower than for other seasons (Fig. 4). This probably has to do with the fact that during winter twigs from Scots pine (*Pinus sylvestris* L.) and deciduous trees (both with relatively low ^{137}Cs concentration) are the dominant food of moose (Cederlund et al. 1980, Bergström and Hjeljord 1987). The winter diet is almost the same among individuals and years, so are the ^{137}Cs concentration in moose also the same during winters (Fig. 4a,b). The ^{137}Cs levels in September depend on food utilization during the summer and early autumn when the diet is more complex (Cederlund et al. 1980, Bö and Hjeljord 1991) so this may explain the large variation in ^{137}Cs concentration in moose during September.

In Paper V, I show that the fluctuation between years in ^{137}Cs levels in moose shot during the early hunt is correlated with the summer weather. The temperature is positively correlated with the ^{137}Cs concentration in moose. The explanation for this could be that the moose are heat stressed and during hot periods cool off in ponds or in shaded mature forests and while they eat common plants (of high ^{137}Cs levels), instead of standing in the sun on a clear-cut forest-area or in a farmland and eating herbs and crops with low ^{137}Cs levels (Marcum and Scott 1985, Renecker et al. 1986, Bothmer et al. 1990, Bö and Hjeljord 1991, Paper III).

One factor often suggested to explain high ^{137}Cs levels in moose is that the ^{137}Cs concentration would be elevated during years with a high abundance of fungi (which are high in ^{137}Cs). There has so far been little evidence for this hypothesis (Cederlund et al. 1980, Johanson et al. 1994), but it cannot be excluded because some fungi do have high ^{137}Cs concentration compared to ordinary plants (Karlén et al. 1991). If moose included only a few percent fungi in the diet it would elevate the concentration in moose considerably. However, my data from rumen analysis (Paper II), the correlation with weather factors (Paper V), and the seasonal changes between years (Fig. 4) does not support this hypothesis. Thus, it seems more likely that the large differences among years in ^{137}Cs could be explained by a shift in habitat selection, and the resulting changes in diet alone.

Long term (more then 10 years after the fall-out)

To predict the long term levels of ^{137}Cs in the forest ecosystem, bilberry and pine samples collected during 1984 and 1985 were analysed for ^{137}Cs levels. The ^{137}Cs from before Chernobyl comes from the atmospheric testing of nuclear bombs in the 1950's and 60's (Edvardson 1991).

The ^{137}Cs concentration in bilberry and pine samples collected before the Chernobyl accident differed greatly between different habitat types. The pine (2.5 m high, 33 years old) shoots sampled from a bog had a ^{137}Cs concentration around 500 Bq/kg dry mass whereas pine collected from a young forest (2.5 m high, 8 years old) had a ^{137}Cs concentration of only 20 Bq/kg per dry mass (Paper IV). This suggest that the difference in ^{137}Cs levels among habitats may increase with time. In Paper III it is shown that the ^{137}Cs level in bilberry plants differs between young and mature forest in 1989-90 although it did not differ in 1986. We could then expect that the difference between individuals in ^{137}Cs levels and between years could increase with time (see above).

During 1986 hunters were asked not only to send samples from the 1986 moose hunt, but also moose meat from 1985 still in their freezers. This meat had a mean ^{137}Cs concentration of 33 Bq/kg. The samples from before the Chernobyl accident were easily discernible by using ^{134}Cs concentration which was zero in the pre-Chernobyl samples while 1/3 of the total cesium in the samples from after (Persson 1987). Deposition from atmospheric tests of nuclear bombs during 1950's and 60's was about 3000 Bq/m^2 over Sweden (Edvardsson 1991). Note that if only the physical half life (30.2 year) was involved the levels should be around 1500 Bq/m^2 in the Västerbotten area when the accident in Chernobyl occurred in 1986. This makes a (theoretical) aggregated transfer factor, i.e. (Bq/kg ^{137}Cs in moose)/(Bq/m^2 ^{137}Cs fall-out where the moose was killed), of about 0.02 for the moose killed in 1985. When comparing this with the ^{137}Cs concentration in moose and fall-out after the Chernobyl accident 1986-1993 (Paper V, Fig. 4), the aggregated transfer factor was the same. This suggests that no ecological half life needs be estimated since this is the same aggregated transfer factor that would be expected if physical halflife was the only factor that influenced ^{137}Cs concentration in the moose. It thus seems that the ^{137}Cs will stay in the moose population until it is eliminated by its radioactive decay. This means that it will take about 120 years to reach the preChernobyl ^{137}Cs concentration in the moose population of Västerbotten. During this time we will have some years with high ^{137}Cs levels in moose and some with lower levels.

CONCLUSIONS

As expected there was a positive correlation between the fall-out of cesium from Chernobyl and the concentration in moose. There also existed age-dependent differences in ^{137}Cs concentration between moose calves and adults, with calves tending to have higher levels than adults. Some differences also existed between the sexes although they were smaller (females had higher ^{137}Cs concentration than males).

The differences within a year in ^{137}Cs concentration between moose of the same age and sex is largely due to the fact that individual moose consume plants of different ^{137}Cs concentration, due to the use of different habitat types. The differences in ^{137}Cs levels between years probably depends on between-year variation in habitat utilization due to the weather. During warm summers and autumns, moose utilize more wetland (cool habitats during warm days) or mature forests (which are shady during sunny days) and the plants (of high ^{137}Cs levels) found there, whereby their meat will have a higher ^{137}Cs concentration. If, during colder, summers moose instead use farmlands or clear-cut forest areas and consume the plants (of low ^{137}Cs) found there, a lower ^{137}Cs concentration will be the case.

The ^{137}Cs concentration in moose fluctuates seasonally and yearly with diet and habitat use, i.e. there are high concentration and large differences between moose killed during the plant growing season, but low values and low difference for moose killed during the winter (between and within years). These seasonal fluctuations occur because moose diets during winter are dominated by pine and deciduous twigs (of low ^{137}Cs), which during spring, summer and autumn the diet is composed of many different plant species.

The analyses of ^{137}Cs in moose and its food plants from before and after the Chernobyl accident indicate that the ^{137}Cs from Chernobyl will stay in the northern forest ecosystem for a long time. The physical decay (30.2 years) seems to be the major factor for its disappearance from the ecosystem. I also expect that the fluctuation between years in the ^{137}Cs concentration will persist, although decrease in maximum values.

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REFERENCES

Ahti, T., L. Hämet-Ahti and J. Jalas, 1968. Vegetation zones and their sections in northwestern Europe. Annales Botanici Fennici 5:169-211

Åman, B. 1994 Radio caesium in reindeer (*Rangifer tarandus tarandus*) after the fall-out from the Chernobyl accident: Dissertation Swedish University of Agricultural Science. Sweden. Uppsala 1994

Bakunov, N.A. 1989. Accumulation of ^{137}Cs in plants and characteristics of its behavior in soils. Soviet Soil Science 21:71-78

Beier, P. 1987. Sex differences in quality of white-tailed deer diets. J. Mamm. 68:323-329

Belovsky, G.E., 1978. Diet optimization in a generalist herbivore: The moose. Theor. Pop. Biol. 14:105-134.

Bergman, R., K. Danell, A. Ericsson, H. Grip, L. Johansson, P. Nelin and T. Nylén. 1988. Uptake, turnover and transport of radioactive caesium (^{137}Cs and ^{134}Cs) in a boreal forest ecosystem. FOA rapport E40040, Umeå, Sweden ISSN 0281-9945. (In Swedish with Eng. Abstr.).

Bergman, R., T. Nylén, P.Nelin, T., Palo (in press), Herbivory and transport of radiocesium in the forest ecosystem. The dynamic behaviour of radionuclides in forests The Sci. of the Tot. Environ.

Bergström, R. and O. Hjeljord. 1987. Moose and vegetation interaction in northwestern Europe and Poland. Swedish Wildlife Research Suppl. 1:213-228

Bjärvall, A. and S. Ullström. 1985. Däggdjur. Alla Europas arter. Wahlström & Widstrand. Stockholm, Sweden (In Swedish) . 240 p.

Bö, S. and O. Hjeljord 1991. Do continental moose ranges improve during cloudy summers? Can. J. Zool. 69:1875-1879

Bothmer, S. von, K.J. Johanson and R. Bergström. 1990. Cesium-137 in moose diet; considerations on intake and accumulation. Sci. of the Tot. Environ. 91:87-96

Bunzl, K. and W. Kracke 1986. Accumulation of fall-out ^{137}Cs in some plants and berries of the family Ericaceae. Health Phys. 50:540-542

Bunzl, K. and W. Kracke 1989. Seasonal variatin in soil-to-plant transfer of K and fall-out $^{134,137}Cs$ in peatland vegetation. Health Phys. 57:573-600

Cederlund, G., H. Ljungqvist, G. Markgren, G. and F. Stålfelt. 1980. Foods of moose and roe deer at Grimsö in central Sweden - Results of rumen content analyses. Swed. Wildl. Res. 11:169-247

Coughtrey, P.J. and M.C. Thorne. 1983. Radionuclide distribution and transport in terrestrial and aquatic ecosystems. A critical review of data. A.A Balkema Rotterdam, Netherlands.

Davis, J.J. 1963. Cesium and its relationships to potassium in ecology. In: Radioecology Proceedings of the First National Symposium on Radioecology held at Colorado State University, Fort Collins, Colorado, September 10-15, 1961. Ed. Schultz V. and A.W. Klement Jr. Reinhold Publishing Corporation New York. USA. pp.539-556

Edvardsson, K. 1991. Fall-out over Sweden from the Chernobyl accident. In: The Chernobyl fall-out in Sweden. Ed. Moberg, L., Swedish Radiation Protection Institute, Stockholm, Sweden.

Gorham, E. 1959. A comparison of lower and higher plants as accumulators of radioactive fall-out. Can. J. Bot. 37:327-329.

Hanson W.C. 1985. Ecological processes in the cycling of radionuclides within arctic ecosystems. In: Studies in Polar Research. Arctic Air Pollution. International symposium 1985. Cambridge. England. UK Sept. 2-5. Ed. B. Stonehouse, Cambridge University Press pp.221-228.

Holleman D.F., J.R. Luick and F.W. Whicker. 1971. Transfer of radiocesium from lichen to reindeer. Health Phys. 21:657-666.

Howard, B.J., N.A. Beresford and K. Hove. 1991. Transfer of radiocesium to ruminants in natural and semi-natural ecosystems and appropriate countermeasures. Health Phys. 61:715-725.

Johanson, K.J. and R. Bergström, 1989. Radiocaesium from Chernobyl in Swedish moose. Environ. Pollut. 61:249-260.

Johanson, K.J., R. Bergström, O. Eriksson and A. Erixon. 1994 Activity concentration of ^{137}Cs in moose and their forage plants in Mid-Sweden. J. Environ. Radioact. 22:251-267.

Jordan, P.A., A.S. Botkin, S. Dominski, H.S. Lowendorf, H.S and G.E. Belovsky, 1973. Sodium as a critical nutrient for the moose of Isle Royal. Proc. N. Am. Moose Conf. Workshop. 9:1-28.

Karlén, G., K.J. Johanson and R. Bergström. 1991. Seasonal variation in the activity of ^{137}Cs in Swedish roe-deer and in their daily intake. J. Environ. Radioact. 14:91-103.

Kitching, T., D. DiGregorio and P. VanVoris, 1975. A review of the ecological parameters of radionuclide turnover in vertebrate food chains. National Symposium on Radioecology 4. Radioecology and Resources. Eds. S.E. Cushing and Dowden, G.I. Hutchinson & Ross, Stroudsburg, Pennsylvania, USA.

Leptich, D.J. and J.R. Gilbert, 1989. Summer home range and habitat use by moose in northern Maine. J. Wildl. Manage. 53:880-885 .

Lidén, K. and M. Gustafsson. 1967. Relationship and seasonal variation of ^{137}Cs in lichen, reindeer and man in northern Sweden 1961-1965. In: Radioecological concentration Process. Eds. B. Åberg and F.P. Higgate, Oxford Pergamon Press England pp:193-208.

Markgren, G. 1966. A study of hand-reared moose calves. Viltrevy 4:1-42.

Marcum, C.L. and M.D. Scott. 1985. Influences of weather on elk use of spring-summer habitat. J. Wildl. Manage. 49:73-76.

Mattson, L. 1990. Hunting in Sweden: Extent, economic values and structural problems. Scand. J. For. Res. 5:563-573.

Mayes R.W. 1989. The quantification of dietary intake, digestion and metabolism in farm livestock and its relevance to the study of radionuclide uptake. Sci. of the Tot. Environ. 85:29-51.

McGee, E.J., H.J. Synnot and P.A. Colgan, 1993. A new method for prediction of radiocaesium levels in vegetation: Evidence from Irish Uplands. J. Environ. Radioact. 18:53-70.

Nelin P. and T.R. Palo. 1989. Factors influencing caesium-137 levels in moose (*Alces alces*) and small game in northern Sweden. In:The Radioecology of Natural and Artificial Radionuclides. Proceedings of the XVth Regional Congress of Internationel Rradiation Protection Association. Visby. Sweden. 10-14 September 1989. Ed. W.Feldt. pp.153-158.

Peek, J.M. 1974. A review of moose food habits studies in North America. Naturaliste Can. 101:195-215.

Persson, C., H. Rodhe and L.-E. De Geer. 1987. The Chernobyl accident, a meteorological analysis of how radionuclides reached and were deposited in Sweden. Ambio 16:20-31.

Renecker, L.A. and R.J. Hudson. 1986. Seasonal energy expenditures and thermoregulatory responses of moose. Can. J. Zool. 64:322-327.

Scheppard, S.C. and W.G. Evenden. 1988. The assumption of linearity in soil and plant concentration ratios: An experimental evaluation. J. Environ. Radioactivity. 7:221-247

Schwartz, C.C, W.W Regelinand A.W. Franzman. 1984. Seasonal dynamics of food intake in moose. Alces 20:223-244.

Schwartz, C.C., W.L. Regelin, A.W. Franzmann and M. Hubbert. 1987. Nutritional energetics of moose. Swe. Wildl. Res. Suppl. 1:265-279.

Shultz, V. and A.W. Klement Jr. 1963. Radioecology. Radioecology Proceedings of the First National Symposium on Radioecology held at Colorado State University, Fort Collins, Colorado, September 10-15, 1961. Ed. Schultz V. and A.W. Klement Jr. Reinhold Publishing Corporation New York. USA.

Swedish Geological Company. 1986. Map (scale 1:1 000 000) produced by the Swedish Geological Company and based on measurements from aircraft during May-October 1986. Swedish Geological Company, Uppsala, Sweden

Wilkinson, L. 1988. SYSTAT: The System for Statistics. Evanston, Illinois, USA

Zach, R., J.L. Hawkins and K.R. Mayoh. 1989. Transfer of fallout cesium-137 and natural potassium-40 in a boreal environment. J. Environ. Radioact. 10:19-45

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Previous publications

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