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INTRODUCTION

On April 26 1986, a reactor unit of 1000 MW (graphite moderated, light water cooled) in the Chernobyl Power Station, USSR, ignited after an explosion and substantial amounts of radioactive materials were released. Air masses moved towards Scandinavia and on April 28 a radioactive fallout was detected in Sweden. The Swedish National Institute of Radiation Protection (SSI) and the National Defence Research Institute (FOA) immediately started a radiation monitoring program, followed a few days later by other laboratories and universities.[1,2,3,4,5,6]

The insertion and subsequent accumulation of radioactive substances in ecosystem focuses attention on a highly complex set of natural processes. In a health perspective, it poses particular concern for the food chain. Therefore, a special "Chernobyl group" within the National Food Administration (SLV) started work to deal with the situation that had arisen. In order to issue action guidelines and to reduce the doses from intake of contaminated food, an extensive program of measurements was started by SLV in co-operation with this Department. The primary aim of the monitoring was to obtain a detailed survey of contents of radionuclides in a wide variety of foodstuffs, including vegetables, fruits, edible wild plants, dairy products, wild and tame animals.

The entire program succeeded thanks to the excellent collaboration between the "Chernobyl group" and this Department: daily contacts were immediately established and practical routines were soon operative in a constructive yet informal atmosphere. The results presented in this report cover the period May-November 1986 and concern only the food samples collected in order to be able to issue recommendations to the public in the most contaminated areas. The work carried out by the SLV and particularly by the "Chernobyl group" has been summarized elsewhere.[7,8]

Content of radionuclides in fallout

The fallout contained both fission and activation products expected in the situation of an accidental release from a nuclear reactor, mainly ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{99}Mb, ^{103}Ru, ^{106}Ru, ^{131}I, ^{132}I, ^{132}Te, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce and ^{144}Ce. Both alpha-, beta- and gamma-emitting nuclides were present, with half-lives ranging from hours to thousands cf years; Fig. 1 shows the spectrum of gamma-emission from a grass sample collected at this Department on May 10. Even ^{110m}Ag, which is not a fission fragment, was detected: as also suggested by others,(9,10) it seems possible that this nuclide might have been produced by neutron activation of reactor control details via the ^{110}Cd (n,p) ^{110}Ag reaction. The absence of substantial information on the construction details of the Russian reactor made it difficult to verify this interpretation.

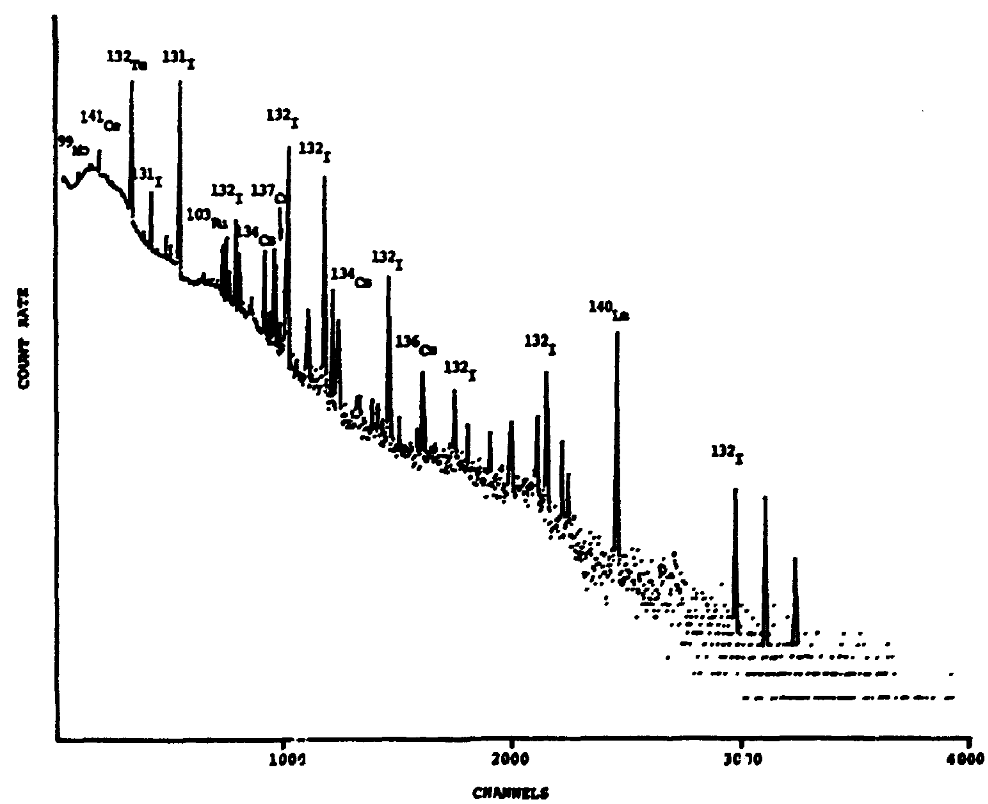

Fig. 1. Gamma spectrum of a grass sample showing some of the nuclides in the fallout.

On the basis of the measured activity ratio $^{134}Cs/^{137}Cs$, it was possible to perform a core inventory of the different nuclides and estimate the mean operation time of the Chernobyl reactor at about one year.(11,12)

Preliminary investigations on the concentration of ^{90}Sr were carried out, resulting in levels at about 1% of corresponding Cs-figures.(13) A few analyses of transuranic elements were also made, showing very small amounts (0.01% of Cs-figures) of ^{239}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Cu and ^{244}Cu.

Geographical distribution

The transport and dispersion of radioactive materials in the atmosphere was influenced by several parameters, such as release rate, plume configuration, wind direction and meteorological conditions.(14,15) However, weather was the factor that mainly influenced the surface contamination: dry deposition resulted in lower ground activity, while in the most contaminated areas rainfall predominated when the cloud passed. In order rapidly to obtain a survey of the radioactive deposition, the Swedish Geological Co. mapped the soil deposition by aircraft,(16) flying at 150 m above ground and measuring the gamma emession from May 9 to June 3. This is shown in Fig. 2, where the contamination of ^{134}Cs is selected to separate the Chernobyl fallout from the residual level resulting from the atmospheric testing of nuclear weapons during the 1960's.

Action guidelines

At the very first stage of the emergency, the action level decided by SSI was based on the expected dose calculated on the results of environmental monitoring. Attention was first focused on dairy cows and an extensive mapping of grass deposition was started to reduce the nuclide accumulation in milk. As the outdoor season was just starting at the time of the accident, grazing restrictions were issued in the areas where the grass activity exceeded 3 kBq/m^2 for ^{131}I and 1 kBq/m^2 for ^{137}Cs.

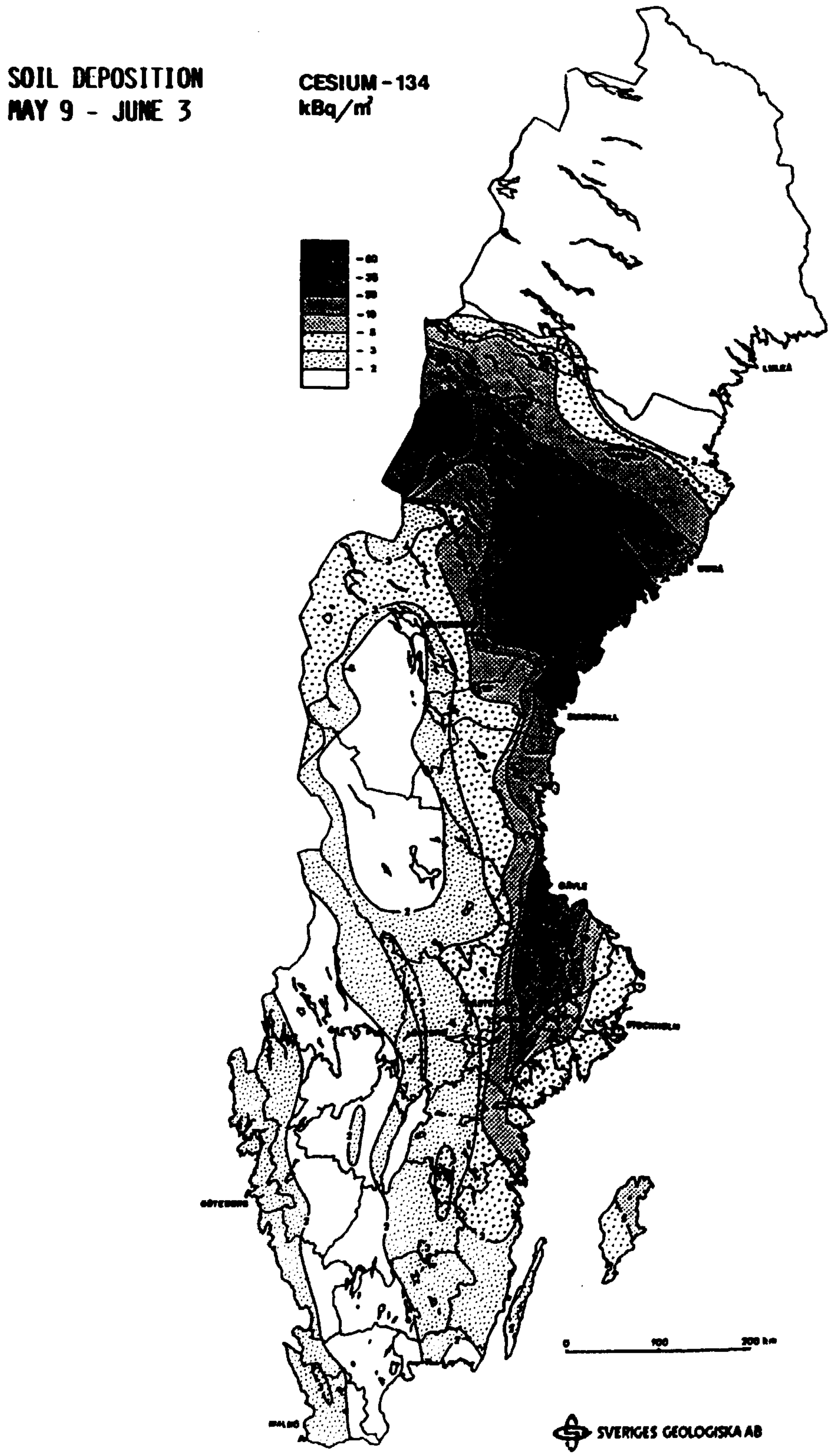

Fig. 2. Gamma-measurement of soil deposition made by aircraft.

SSI continuously controlled the nuclide content in milk and the Dairy Associations also started a monitoring program of their own. Generally, the nuclide concentration in dairy milk increased when outdoor grazing started but stabilized soon at low levels, depending mainly on diluting effects, i.e. lower nuclide specific concentration in grass due to growth.

As the activity of ^{131}I decayed rapidly, the more critical ^{134}Cs (half-life 2 years) and ^{137}Cs (half-life 30 years) were take in consideration. The maximum concentration level of radioactivity permitted in foodstuffs offered for sale was placed at 300 Bq/kg (fresh weight) ^{137}Cs by SLV. This action level was issued only as a recommendation for private hunting and angling but constituted a restriction for marketing of game and fish products and generally all food marketed as ready for public consumption.

The figure 300 Bq/kg ^{137}Cs corresponds to about 450 Bq/kg for both ^{134}Cs and ^{137}Cs together, in some agreement with the value followed in EEC countries (600 Bq/kg).

The background to the Swedish action level can be briefly summarized in the following assumptions:

1) to 90% the dose from food intake was made up of the sum of ^{134}Cs + ^{137}Cs
2) the ratio $^{134}Cs/^{137}Cs$ at that time was about 0.5
3) the following relationship was considered valid for children and adults:

$$75000 \text{ Bq } ^{137}Cs \text{ give } 1 \text{ mSv}$$
$$50000 \text{ Bq } ^{134}Cs \text{ give } 1 \text{ mSv}$$

The goal was that the dose from food intake should not exceed 5 mSv during the first years and 1 mSv during the following years.[17,18] It can be easily calculated that a mean intake of 100 Bq/day ^{137}Cs limits the annual dose to less than 1 mSv.

It has been observed[19] that this dose calculation might have been overestimated since it was based on infants as the most exposed group instead of older children, who have a less rapid metabolism. Further discussions about this matter can be found elsewhere.[17,19]

THE MEASUREMENTS

Sample preparation

The food samples were collected in the most contaminated areas under the supervision of SLV and with the collaboration of local county authorities and then sent to our Department for measurements. The laboratory procedures for sample handling and preparation followed established routines[20,21] and were concentrated upon reducing the risk of contamination and minimizing sources of error. These operations were both time-demanding and tedious yet very important for producing consistent results. After registration, the edible parts were separated from non-edible portions, thus eggs were shelled, fish were filleted, meat was deboned, etc. Then, these parts were weighed, chopped into small pieces to form homogeneous mixtures and uniformly placed into cylindrical plastic containers. Great care was used to fill the containers to exact volumes and thus ensure correct and reproducible geometries.

As the quantity of sampled material varied greatly, six different container sizes were used, with volumes of 35, 90, 180, 330, 850 and 1000 ml (the largest being a "Marinelli" beaker). In some cases, e.g. with berries, large volumes were preferred to small ones, in order to obtain more representative results.

Detection procedure

Each of the six geometries was calibrated with certified standard solutions by Amersham Int. diluted in 0.4 M nitric acid. As water content in fresh samples varies, these calibrations were also compared with similar ones mixed in sawdust to assess the degree of self-absorption. Results obtained indicated, within experimental uncertainties, a difference of 10% for ^{131}I, yet the deviation was negligible for the gamma energies of ^{134}Cs and ^{137}Cs, therefore no correction for self-absorption was made for these nuclides.

The gamma emission rate was measured for 10 mins with two hyperpure Ge-detectors (ORTEC, PGT) in a low-background laboratory with 70 cm thick walls of especially selected concrete.(22) Furthermore, the detectors and the samples were surrounded by a shielding consisting of 1 mm copper, 5 cm iron and 10 cm low-active lead. The whole arrangement ensured very low background for counting low activities at high efficiency. The output signals of the detectors were fed into two 4096-channels spectrometry analyzers (ORTEC Adcam, Nuclear Data ND 600) placed in a separate control room to prevent the operator from interferring with the measurement.

The Cs-content was calculated using the 661.6 keV-peak for ^{137}Cs and 795.8 keV for ^{134}Cs. The ratio $^{134}Cs/^{137}Cs$ was determined by measuring some samples of surface deposition at a distance from the detector of 25 cm, to avoid coincidence summing effects.(23,24,25) The result obtained with this procedure was 0.6 (at the end of May). However, to increase the full-energy peak efficiency, all the samples were measured by placing them directly on the detector and at this distance the ratio was 0.5, a divergence due to true coincident summing of the ^{134}Cs gamma-ray cascade. The effect, unrelated to the count rate, depends strongly on the solid angle subtended by the detector: at small source-to-detector distances the probability of coincidence for ^{134}Cs photons is higher, thus resulting in count loss in constituent full energy peaks. In our measurements this effect influenced only the ratio $^{134}Cs/^{137}Cs$, while no efficiency correction was necessary in Cs-determination, since the standard calibration samples had the same geometry as the analyzed material.

Statistics of the measurements

The random nature of radioactive decay leads to uncertainty about the accuracy of radiation measurements. The standard counting error (Poisson statistics) E for a single measurement is defined[26] as $E = \sqrt{C}$, where C is the total amount of counts. Table 1 lists the standard error values of measurements at different activity levels. It is evident that long measuring times result in smaller uncertainty. Nevertheless, the aim of determining Cs-contents in as many samples as possible made it unrealistic to use longer counting times than 10 mins and consequently samples with low activity (10-20 Bq/kg) exhibited poor counting rates, i.e. error values of 30-40%. However, this was by no means the rule and for most samples the activity was higher and the statistical error seldom exceeded 10%.

Table 1. Standard error at different activity rates.

ACTIVITY (Bq/kg)	STANDARD ERROR (%)
10	40
50	14
100	11
200	8
300	7
500	5
1000	4
5000	2
10000	1

From a practical point of view, a parameter which often is valuable in these measurements is the analytical sensitivity, i.e. the smallest concentration that can be quantitatively determined by this procedure.

This parameter can be assessed in different ways, but is commonly defined[20] as:

$$A = a\frac{C\,t}{V\,e}$$

where: a = conversion factor

C = minimum count rate measurable in time t

t = counting time

V = sample volume

e = detector efficiency

Without entering deeply into the many aspects of this definition, it is evident that the values of these terms depend on many factors and practical conditions such as laboratory background, hardware, available sample quantity, etc. Trials with several combinations of terms were made and in our measurements the value of A was optimized at 2 Bq/kg.

THE RESULTS

Minimum (MIN), maximum (MAX), average (AVG) and standard deviation (STD) of ^{137}Cs content in different biological species are given with three significant digits. The number (NBR) of samples that support the figures is also provided. The exact location and the date of collection of each sample has not been included here, but full information can be found elsewhere.[27] For simplicity the results are reported for each county, even though this distribution did not necessarily coincide with fallout's geographical pattern. Fig. 3 shows the Swedish counties and their codes.

The distribution of activity in foodstuffs largely followed the soil deposition mapped in Fig. 2. As reported in other countries,[28,29,30,31] extreme local variations occurred, mainly depending on the rainfall patterns that dominated during the fallout. Other factors also influenced the results, such as nutrient status, soil pro-

SWEDEN'S COUNTIES

NAME	CODE
Stockholms län	AB
Uppsala län	C
Södermanlands län	D
Östergötlands län	E
Jönköpings län	F
Kronobergs län	G
Kalmar län	H
Gotlands län	I
Blekinge län	K
Kristianstads län	L
Malmöhus län	M
Hallands län	N
Göteborgs och Bohus län	O
Älvsborgs län	P
Skaraborgs län	R
Värmlands län	S
Örebro län	T
Västmanlands län	U
Kopparbergs län	W
Gävleborgs län	X
Västernorrlands län	Y
Jämtlands län	Z
Västerbottens län	AC
Norrbottens län	BD

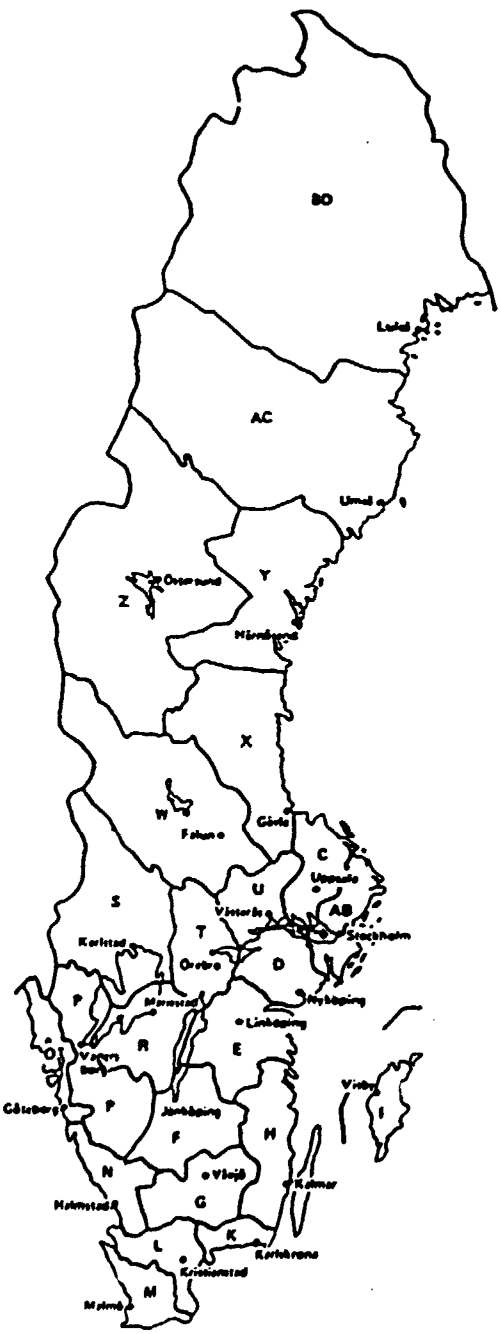

Fig. 3. Sweden's counties.

perties, local field conditions, physiological variations between species, etc.

From a radioecological point of view it would have been desirable to analyze further parameters in each sample. Scarcity of time and the large number of samples (about 9000 by the end of November) made it practically impossible. The results presented here are intended to provide a survey of the situation in Sweden for several foodstuffs after the radioactive fallout.

Cattle and poultry

Generally, the ^{137}Cs-activity in cattle, horse and pig meat was, with few exceptions, low. Higher concentrations were found in animals which mainly graze close to the ground, like goat, lamb and sheep. These results are given in Table 2.

Table 2. Content of ^{137}Cs (Bq/kg wet) in domestic farm animals.

FODDSTUFF	NBR	MIN	AVG	MAX	STD
Cattle	906	<2	56	714	96
Goat	39	<2	167	2230	342
Horse	103	<2	111	838	148
Lamb	131	<2	345	2800	375
Pig	99	<2	14	504	50
Sheep	508	<2	264	3930	477
Chicken	3	20	126	336	148
Egg	21	<2	22	116	29
Turkey	2	23	74	124	51
TOTAL	1812				

As the grazing season ended, the animals were fed with hay which might have been contaminated in certain regions.

Therefore feeding recommendations were issued and intensive controls for the meat to be marketed were started at slaughterhouses.

Variations in Cs-contents occurred seldom in cattle, but were more frequent in sheep, even within the same herd; the detailed results for cattle and sheep in different counties are listed in Tables 3 and 4.

Table 3. Content of ^{137}Cs (Bq/kg wet) in cattle in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	8	<2	20	84	26
AC	139	<2	129	714	156
C	14	<2	31	184	44
D	10	3	40	237	67
E	16	3	16	36	9
F	75	<2	16	64	14
H	22	<2	15	53	15
I	70	<2	22	108	19
K	36	<2	14	77	19
L	58	<2	9	51	9
M	12	<2	8	28	9
N	24	<2	19	48	16
P	12	<2	10	57	19
R	13	<2	6	17	5
S	13	<2	9	26	7
T	18	<2	11	71	16
U	18	<2	49	277	68
X	88	<2	55	604	104
Y	181	<2	105	635	99
Z	69	<2	22	138	33
TOTAL	906				

Table 4. Content of ^{137}Cs (Bq/kg wet) in sheep in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	14	14	30	109	23
AC	27	<2	118	400	136
C	92	<2	366	3930	786
F	6	<2	18	28	9
I	6	12	28	48	13
S	8	<2	37	140	43
U	29	3	218	550	146
W	8	<2	28	56	20
X	67	<2	203	1320	254
Y	137	<2	313	2660	360
Z	113	<2	296	2200	522
TOTAL	508				

Dairy products

Milk control was started during the very first stage of the emergency both by SSI and SLV: the above-mentioned grazing restrictions for cows reduced substantially the accumulation of radiocontaminants in milk.

In addition, the Dairy Associations organized their own monitoring program measuring hundreds of milk samples taken in the different distribution lines. In this way it was possible to map the ^{137}Cs-concentration throughout the whole production, i.e. from farms to consumers, and thereby intervene at the appropriate stage, temporarily eliminating the distribution line that presented increased Cs-levels.

As a result of these countermeasures, the content of ^{137}Cs in milk offered for sale was fairly low and only a limited number of control samples had to be measured. On the other hand, higher levels were recorded in milk from animals which were not subjected to the same preventive control, like goat, or as expected,[32] in products where concentration had occurred, like whey. These results are given in Table 5.

Table 5. Content of ^{137}Cs (Bq/kg wet) in dairy products.

FOODSTUFF	NBR	MIN	AVG	MAX	STD
Milk	76	<2	17	57	13
Milkpowder	7	22	161	367	110
Butter	4	<2	2	3	0
Cheese	19	<2	12	117	25
Whey	2	5	289	573	284
Wheycheese	4	<2	18	59	24
Wheybutter	1	52	52	52	0
Wheypowder	4	13	65	126	41
Goat's milk	2	170	227	283	57
Goat's milk cheese	8	<2	135	856	274
Goat's milk whey	14	<2	222	1050	327
Sheep's milk cheese	4	12	16	20	3
TOTAL	145				

Game

Many samples were collected in order to obtain a view of contamination levels in wild animals, particularly those of interest for hunters, like moose, roedeer and hare. Sometimes only one individual of a certain species could be collected but it was still included in the table to give an idea of the extent of contamination. In this case, the result has to be regarded with caution as large variations occurred in almost all species.

The Cs-content in game is shown in Table 6, whereas Tables 7, 8 and Figs. 4 and 5 show the Cs-contents in hare and roedeer in different counties.

Table 6. Content of ^{137}Cs (Bq/kg wet) in game.

SPECIES	NBR	MIN	AVG	MAX	STD
Badger *(Meles meles)*	3	38	2150	3630	1530
Bear *(Ursus arctos)*	7	62	211	424	142
Beaver *(Castor fiber)*	3	143	526	916	316
Black grouse *(Lyrurus tetrix)*	36	39	522	1990	601
Canada goose *(Branta canadensis)*	20	12	578	3840	1040
Capercaillie *(Tetrao urogallus)*	38	<2	827	3200	801
Crane *(Grus cinerea)*	1	101	101	101	0
Diver *(Colymbus septentrionalis)*	1	107	107	107	0
Eider *(Somateria mollissima)*	20	<2	48	246	79
Fallow deer *(Dama dama)*	3	21	133	278	108
Goldeneye *(Bucephala clangula)*	2	123	348	573	225
Graylag *(Anser anser)*	1	64	64	64	0
Grouse *(Tetrastes bonasia)*	18	<2	506	1790	517
Hare *(Lepus timidus)*	225	<2	1180	12600	1800
Mallard *(Anas platyrhynchos)*	20	18	449	1590	443
Merganser *(Mergus merganser)*	2	52	76	99	24
Moose *(Alces alces)*	561	<2	290	4840	451
Pheasant *(Phasianus colchicus)*	1	24	24	24	0
Rabbit *(Oryctolagus cuniculus)*	2	82	693	1300	611
Pigeon *(Columba oenas)*	5	<2	154	624	236
Ptarmigan *(Lagopus mutus)*	22	<2	246	983	277
Red deer *(Cervus elaphus)*	2	51	76	101	25
Reindeer *(Rangifer tarandus)*	180	12	2210	16400	2950
Roedeer *(Capreolus capreolus)*	439	<2	768	10800	1440
Teal *(Anas crecca)*	2	43	59	75	16
Wild boar *(Sus scrofa)*	3	46	248	452	166
Willow grouse *(Lagopus lagopus)*	5	25	342	598	189
Wood pigeon *(Columba palumbus)*	14	26	382	1100	359
Woodcock *(Scolopax rusticula)*	45	19	1548	16900	2930
TOTAL	1681				

Table 7. Content of ^{137}Cs (Bq/kg wet) in hare in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	4	<2	122	478	205
AC	60	32	936	4250	1000
C	17	<2	761	3160	1080
U	14	<2	777	6420	1770
W	7	56	147	246	62
X	41	40	1040	6860	1430
Y	45	112	2810	12600	2770
Z	26	<2	514	2610	576
TOTAL	225				

Table 8. Content of ^{137}Cs (Bq/kg wet) in roedeer in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	52	<2	67	340	64
AC	12	42	479	1570	505
C	93	<2	746	10800	1480
D	17	4	160	899	198
E	16	<2	61	197	43
H	8	44	83	124	23
T	19	<2	67	116	35
U	68	18	1070	6850	1560
W	31	<2	102	738	134
X	52	85	2230	10300	2310
Y	37	101	1440	4450	1090
Z	14	20	463	1920	539
TOTAL	436				

Woodcock exhibited high contamination rates (almost 17000 Bq/kg) and wide distribution (the standard deviation

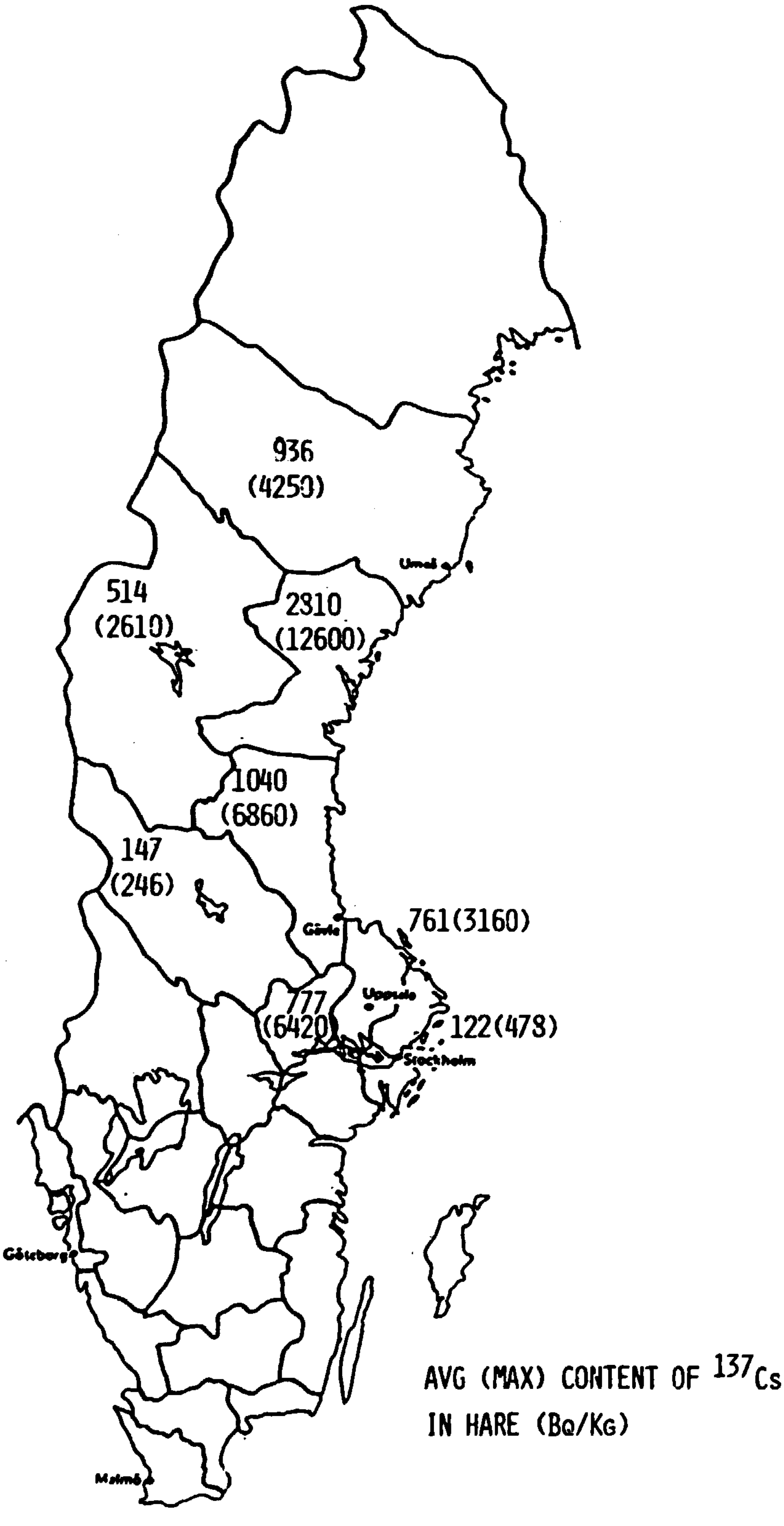

Fig. 4. Geographical distribution of ^{137}Cs in hare.

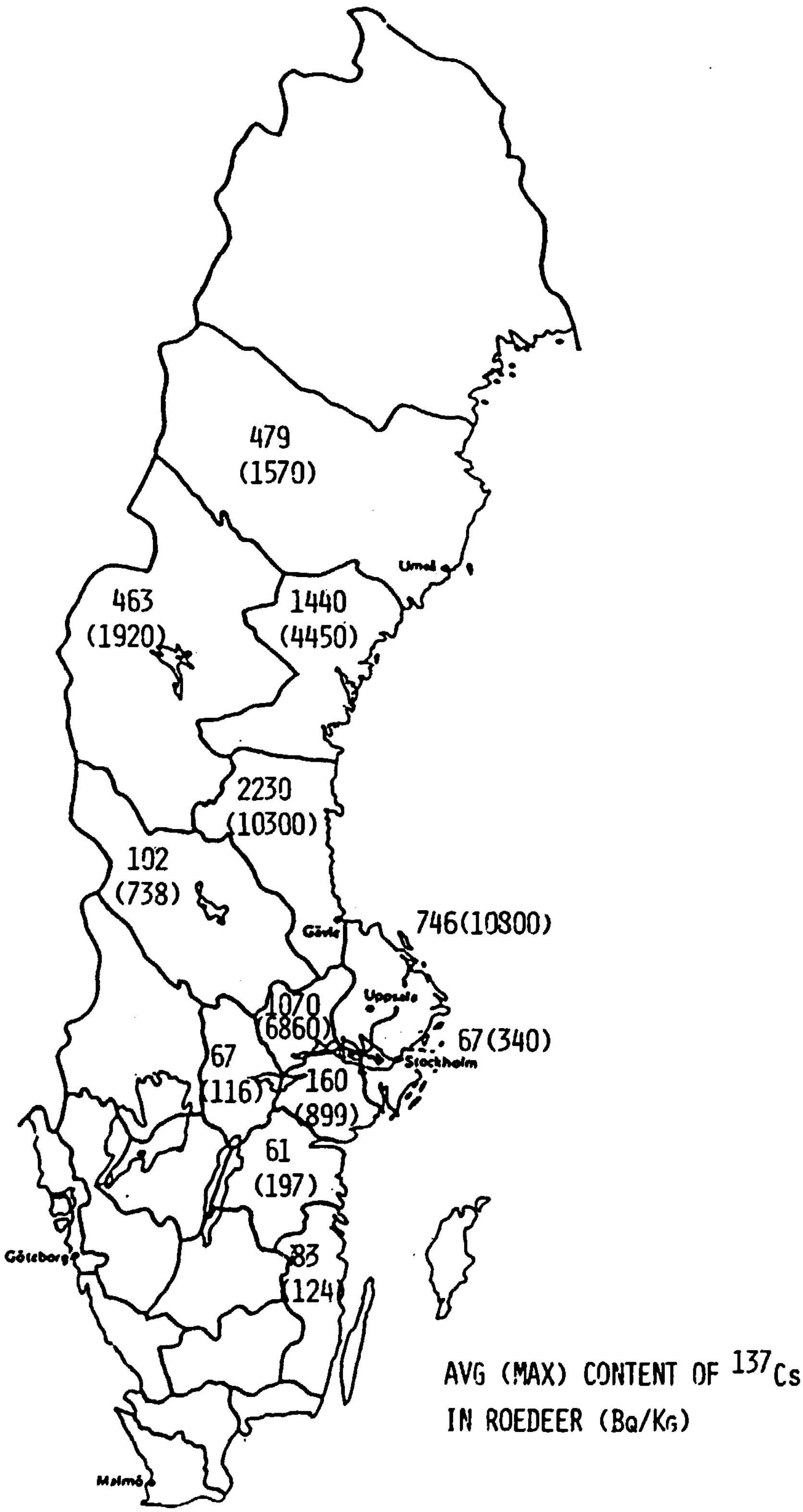

Fig. 5. Geographical distribution of ^{137}Cs in roedeer.

is about twice the mean value). This result seems to be related more to this animal's feeding habits than physiological aspects: other birds like capercaillie and mallard showed lower maximum values and more limited standard deviations. Pecking on the ground might have led to the intake of strongly contaminated food or even soil.

Moose-hunting is quite popular in several regions of Sweden: about 130000 animals are shot annually. Consequently, in certain regions all moose meat which was to be offered for sale had to be inspected. For this purpose the Hunters Associations established monitoring stations that helped their members to examine the hunted animals.

The levels of ^{137}Cs in moose samples collected in different counties are shown in Table 9 and Fig. 6.

Table 9. Content of ^{137}Cs (Bq/kg wet) in moose in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	19	<2	61	171	49
AC	76	<2	276	1550	302
BD	16	7	41	102	26
C	28	33	423	2210	465
D	20	<2	104	249	71
E	12	12	54	87	21
F	13	12	47	106	28
H	11	9	42	76	19
S	20	18	65	135	34
T	20	<2	67	152	43
U	36	14	269	1350	285
W	52	10	55	231	38
X	81	15	660	4840	800
Y	87	16	526	2620	434
Z	58	5	162	906	191
TOTAL	561				

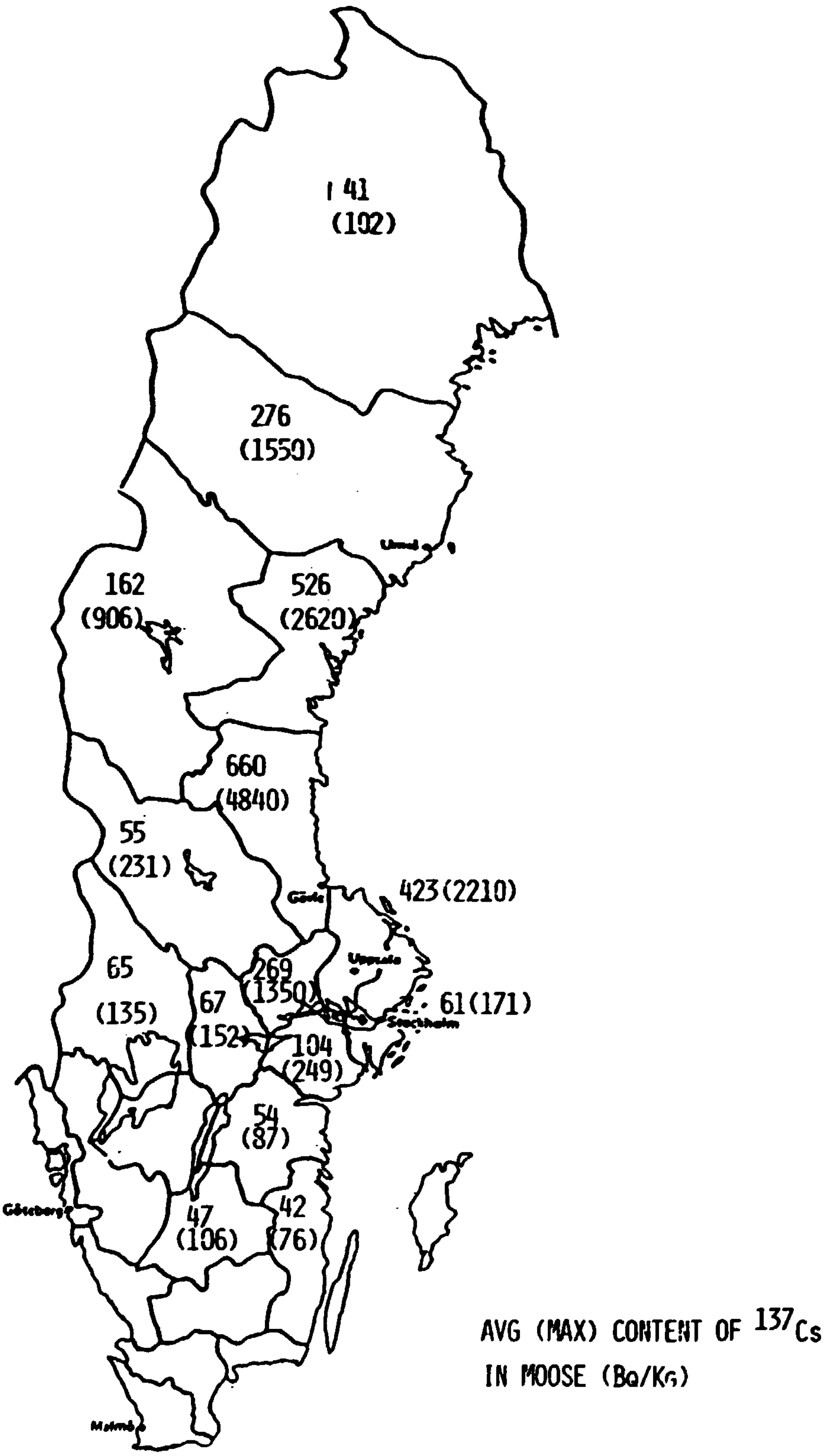

Fig. 6. Geographical distribution of ^{137}Cs in moose.

High rates of ^{137}Cs were recorded in reindeer, creating very serious problems for reindeer breeding and commerce, particularly for the 2500 Lapps in Sweden who work with 275000 reindeer. About 75000 animals were slaughtered in 1986 and an extensive control program was started by SLV at the slaughterhouses to determine the Cs-levels in reindeer meat before sale.

The Cs-accumulation in reindeer meat, caused by a pasture composed mainly of lichens, was widely studied during the sixties after the nuclear weapon explosions in the atmosphere.[33,34,35,36] The time variation of ^{137}Cs in reindeer meat[37] in the period 1961-1980 is plotted in Fig. 7. It can be seen that the relatively high Cs-contents of the mid-sixties have taken more than 15 years to decrease to levels under the threshold of 300 Bq/kg.

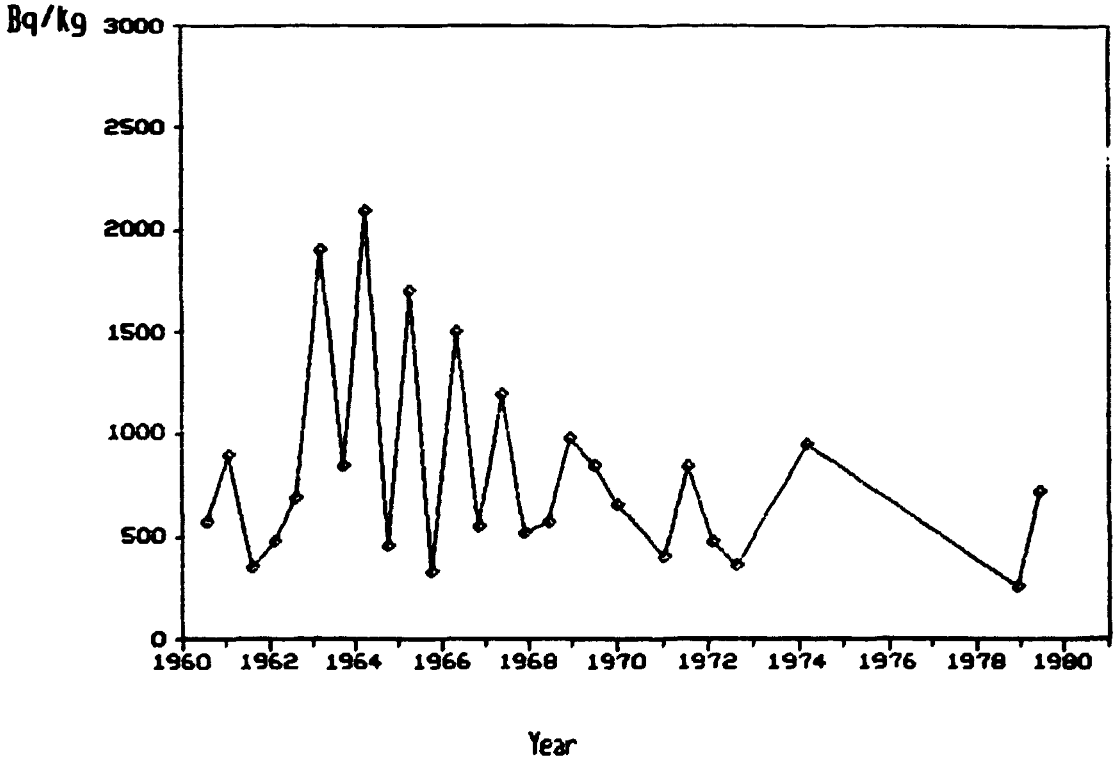

Fig. 7. Time variation of ^{137}Cs-content in Swedish reindeer meat. The differences obtained for autumn and spring slaughters are due to different feeding habits.

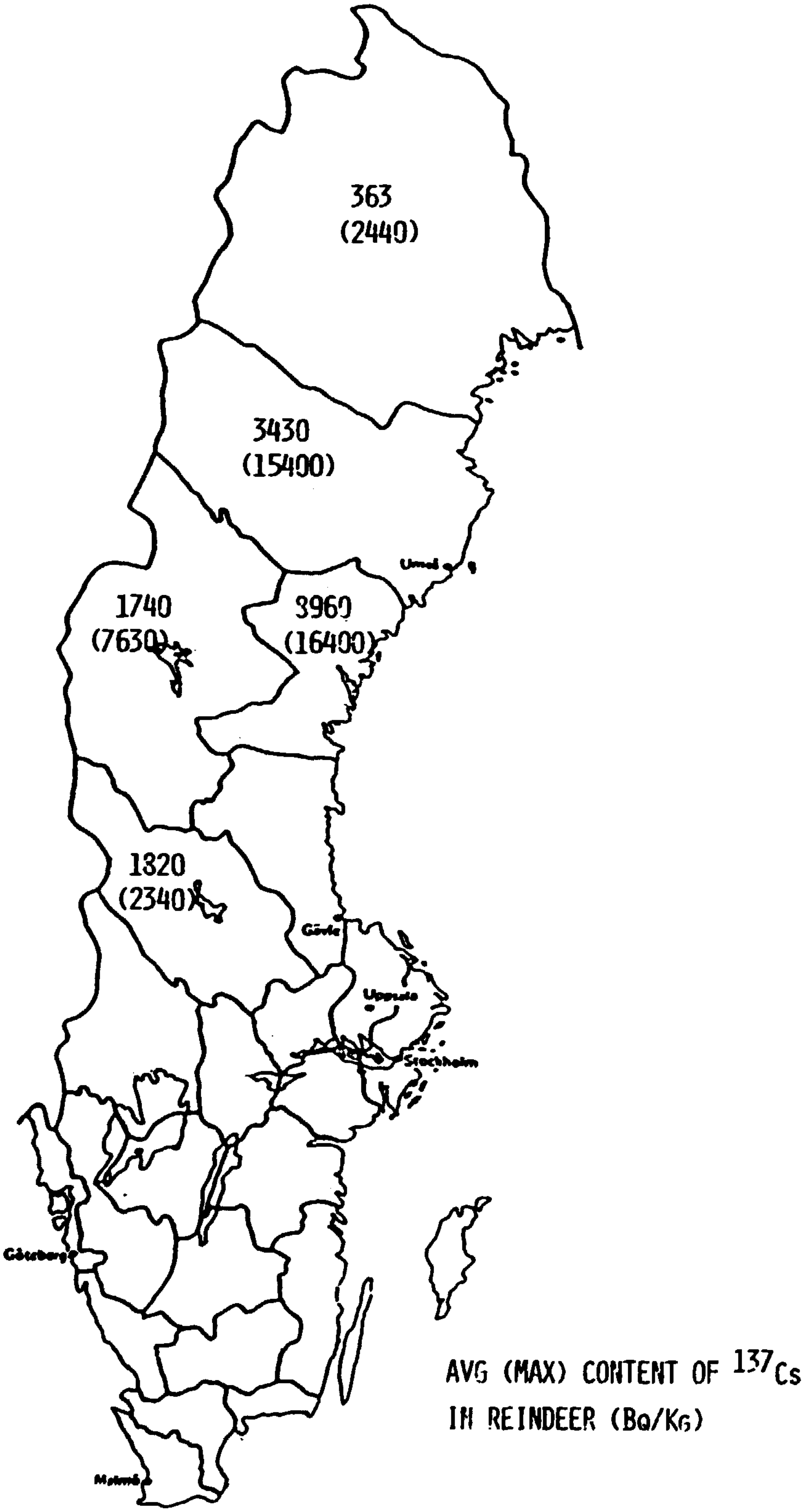

Fig. 8. Geographical distribution of ^{137}Cs in reindeer.

It is clear that after the Chernobyl fallout countermeasures must be taken to avoid an even longer decay to low levels. Investigations in this direction, including alternative feeding experiments, are in progress and the results will be matter for future discussions. The Cs-levels in reindeer in different counties are shown in Table 10 and Fig. 8.

Table 10. Content of ^{137}Cs (Bq/kg wet) in reindeer in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AC	79	12	3430	15400	3350
BD	51	69	363	2440	433
W	6	1320	1820	2340	345
Y	3	3950	8960	16400	5350
Z	41	23	1740	7630	1850
TOTAL	180				

Fish

The levels of ^{137}Cs in fish and some fish products are listed in Table 11.

Table 11. Content of ^{137}Cs (Bq/kg wet) in fish products.

FOODSTUFF	NBR	MIN	AVG	MAX	STD
Crayfish	37	<2	491	2840	713
Fish	1523	<2	1440	48000	2640
Roe (bleak)	13	<2	273	1670	412
Roe (whitefish)	11	23	246	1070	317
TOTAL	1584				

Fish sampling was started very early and mainly concentrated in lakes and rivers of the most contaminated regions, as Cs-content in fish from the open sea was expected to be low.

Table 12 and Fig. 9 show the Cs-levels in fish in different counties.

Table 12. Content of ^{137}Cs (Bq/kg wet) in fish in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	20	<2	135	454	132
AC	295	11	1480	10900	2030
BD	44	<2	226	1030	221
C	54	<2	701	5860	1110
D	11	53	157	317	88
G	1	25	25	25	0
H	2	<2	43	83	41
I	1	10	10	10	0
M	4	<2	11	22	9
N	3	50	72	103	22
O	2	6	14	22	8
R	3	8	13	17	4
S	11	<2	30	95	23
U	35	<2	1170	7520	1780
W	43	13	256	1190	270
X	295	<2	1280	48000	3470
Y	382	<2	1770	18700	2720
Z	315	<2	1880	22600	2800
TOTAL	1523				

The ^{137}Cs values in different fish species are listed in Table 13. The highest activities occurred in perch, bream, trout and char, i.e. fish belonging to closed waters or

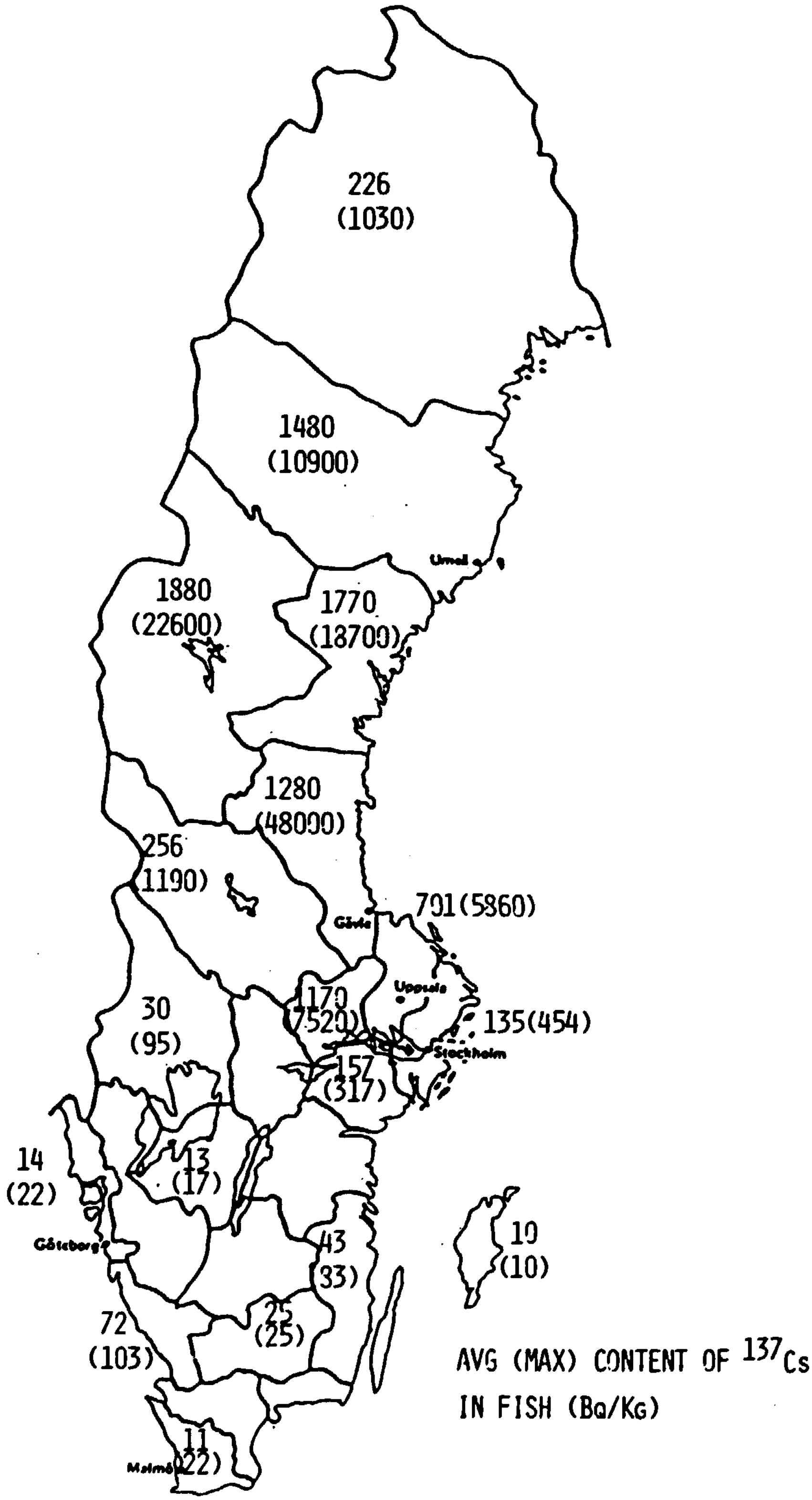

Fig. 9. Geographical distribution of ^{137}Cs in fish.

generally with low hydroenergetic activity where the radioactive deposition could accumulate. The high radiocesium levels were mainly observed in poor waters, following a well-established relationship between the Cs-uptake and water's nutrient status.[38]

Table 13. Content of ^{137}Cs (Bq/kg wet) in different fish species.

SPECIES	NBR	MIN	AVG	MAX	STD
Bream *(Abramis brama)*	8	548	2180	4300	1230
Burbot *(Lota lota)*	11	13	257	769	247
Brown trout *(Salmo trutta fario)*	4	205	338	436	101
Char *(Salvenius alpinus)*	131	<2	2070	10900	2380
Cod *(Gadus morrhua)*	23	<2	54	276	60
Crucian carp *(Carassius carassius)*	3	248	1130	1870	670
Eel *(Anguilla anguilla)*	7	8	179	605	214
Grayling *(Thymallus thymallus)*	40	<2	1140	7690	1480
Herring *(Clupea harengus)*	47	<2	98	287	52
Orfe *(Leuciscus idus)*	3	109	1020	2040	792
Perch *(Perca fluviatilis)*	399	10	2260	48000	3830
Pike *(Esox lucius)*	301	<2	642	11600	1280
Pikeperch *(Stirostedion lucioperca)*	34	<2	204	3660	614
Pollan *(Coregonus albula)*	36	5	549	5190	882
Rainbow trout *(Salmo gairdneri)*	20	<2	129	941	233
Roach *(Leuciscus rutilis)*	4	113	991	2140	730
Salmon *(Salmo salar)*	20	<2	50	298	72
Trout *(Salmo trutta)*	261	<2	2149	18700	2460
Whitefish *(Coregonus lavaretus)*	171	<2	838	20500	2140
TOTAL	1523				

The ^{137}Cs mean concentrations in different species are plotted in Fig 10. Great variations were observed, even among individuals of the same fish species collected in the same lake. This is evident in Fig. 11 where ^{137}Cs

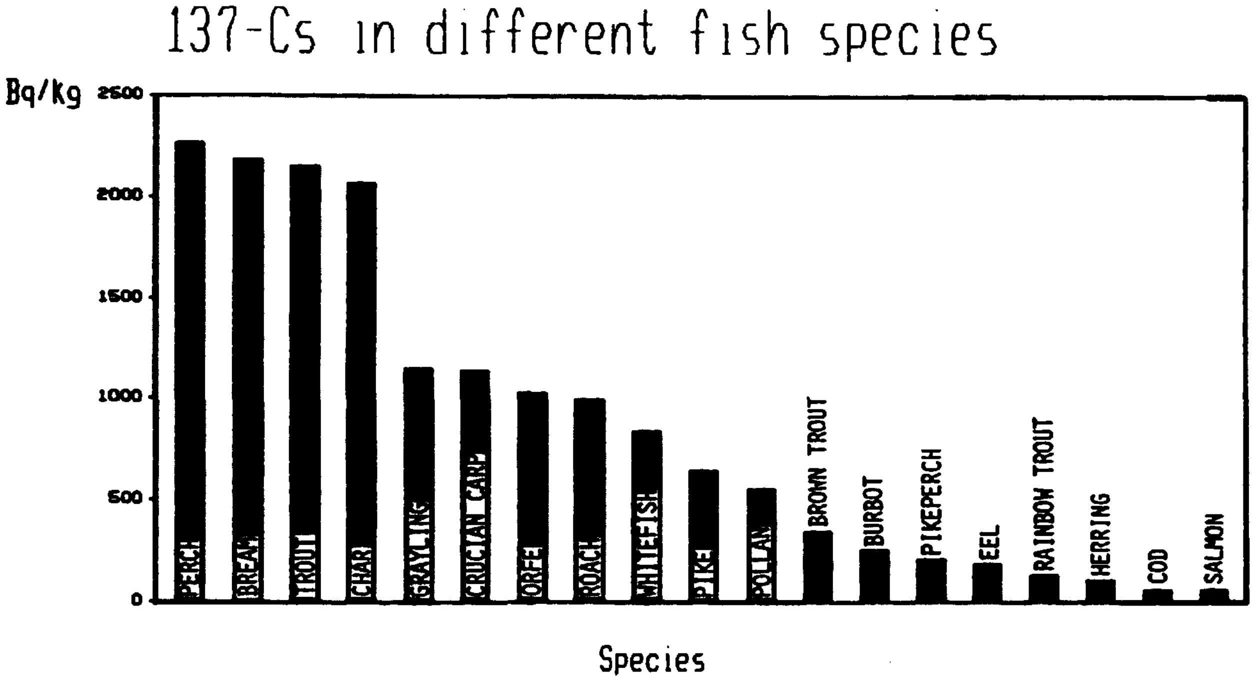

Fig. 10. Mean ^{137}Cs-concentrations in different fish species.

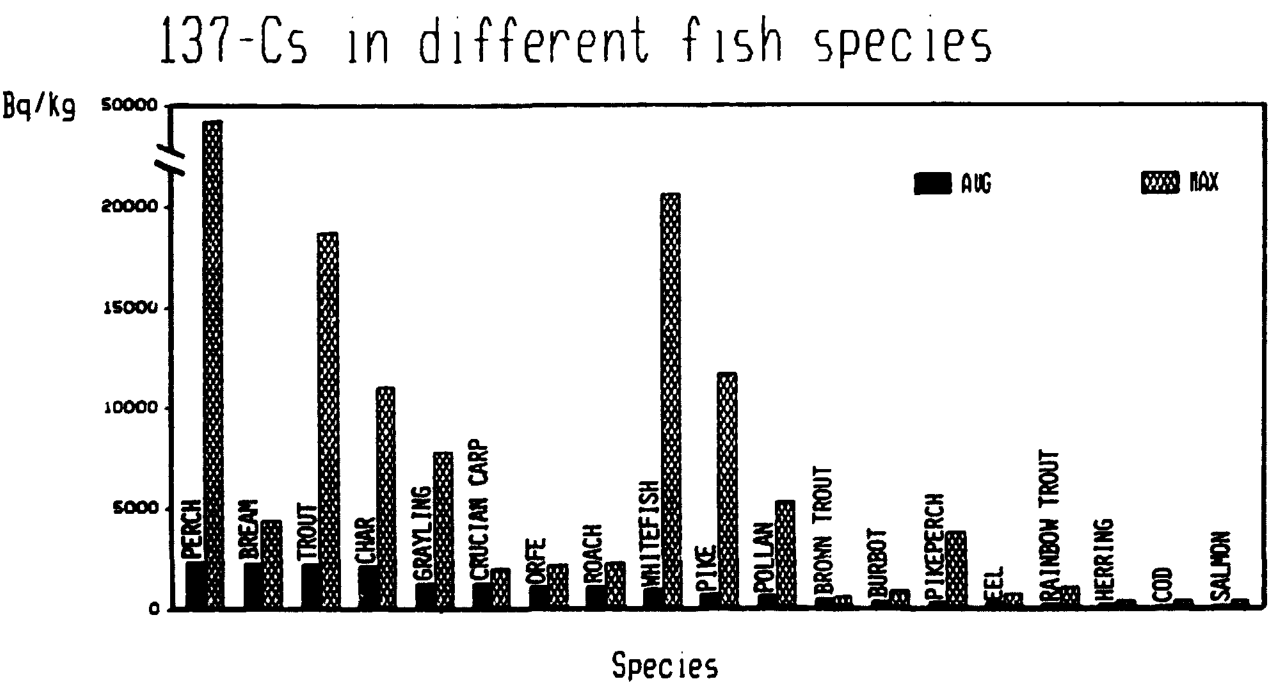

Fig. 11. Comparison between average and maximum ^{137}Cs-concentrations in different fish species.

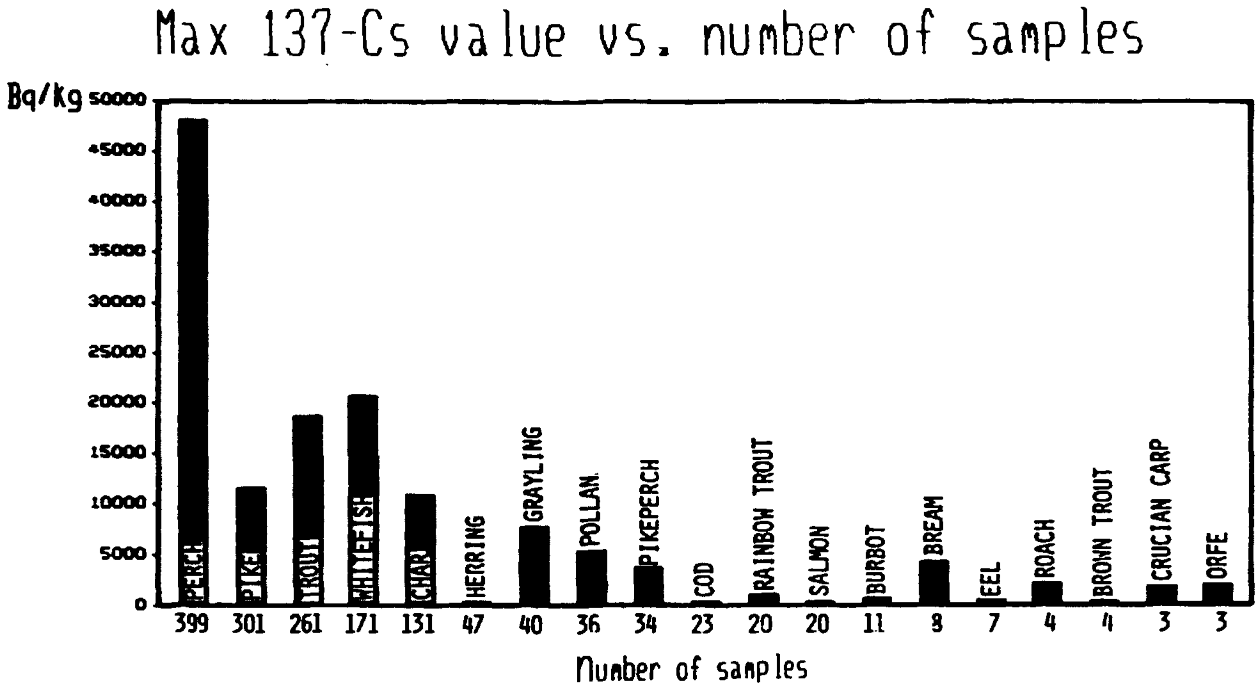

Fig. 12. Relationship between maximum observed Cs-content and number of samples.

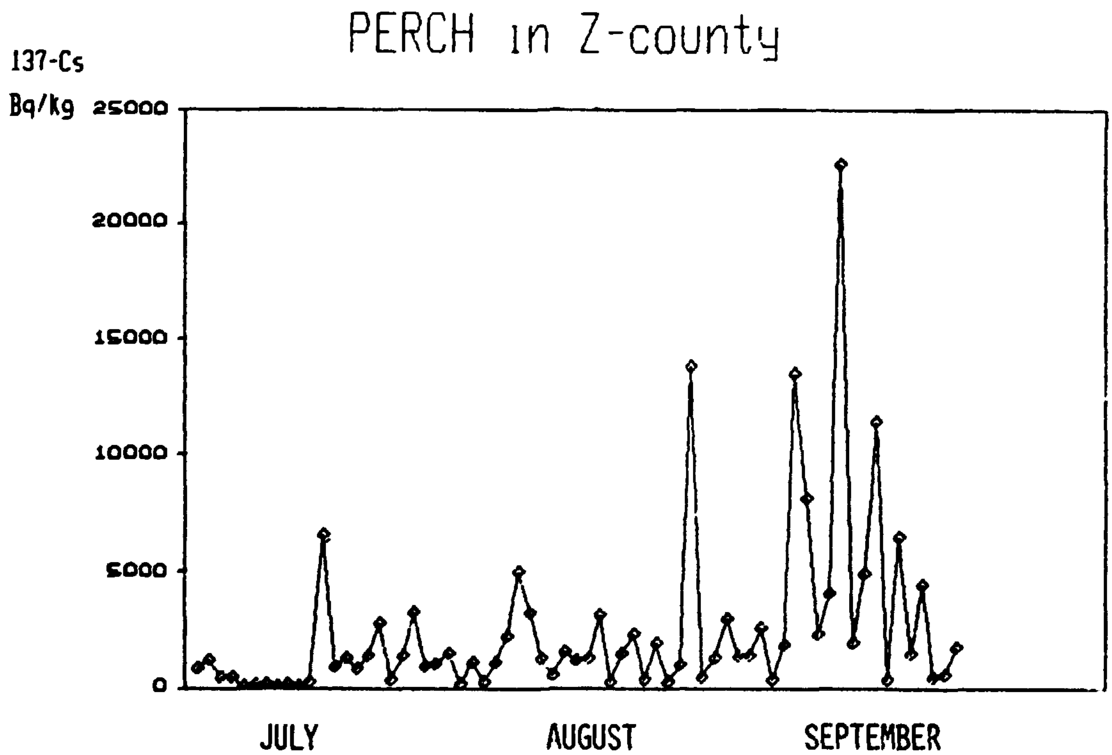

Fig. 13. Time distribution of ^{137}Cs-concentration in perch sampled in Z-county.

average and maximum values for different species do not follow a common path, but for example, high values occur in species with low mean values and vice versa. Further analysis of the data showed that high max-values were somehow correlated with a large number of samples, i.e. with greater probability of collecting individuals with occasional high ^{137}Cs concentration (Fig. 12). Exceptions to this trend were pike, herring, cod, rainbow trout and salmon, confirming the pattern of fishes from coastal or only partially closed waters.

It was also observed that the content of ^{137}Cs tended to increase with time, as can be seen in Fig. 13, where the temporal trend of Cs-content in perch in Z-county is plotted. The higher values observed at the end of the summer might be correlated to the accumulation of fallout products in sediment or perhaps changes in trophic relationships. However, it is likely that the concurrence of several factors influenced this result, making it difficult to-day to evaluate the situation without further investigations.

Vegetables

Measurements made after the harvests at the end of the summer showed that the Cs-content in cereals was low. Tillage and sowing during the spring moved the deposited ^{137}Cs from the soil surface to the root zone making it available for root uptake. Further discussions on this matter are reported elsewhere.(39) Comprehensive measurements of Cs-content in cereals are in progress and further monitoring will be performed next year.

Many different vegetables and berries were collected during their various growing seasons. The activity was generally low and below the action guideline of the SLV (Tables 14 and 15). Only berries that prefer to grow on peat soils, like cloudberries, exhibited increased levels (Table 16 and Fig. 14) and sales were not allowed if the ^{137}Cs-content exceeded 300 Bq/kg.

Table 14. Content of ^{137}Cs (Bq/kg wet) in vegetables.

SPECIES	NBR	MIN	AVG	MAX	STD
Apple (*Malus communis*)	31	<2	46	787	137
Asparagus (*Asparagus officinalis*)	2	<2	5	8	3
Beetroot (*Beta vulgaris rubra*)	18	<2	21	297	67
Carrot (*Daucus carota*)	48	<2	7	140	20
Cauliflower (*Brassica botrytis*)	5	<2	2	2	0
Chard (*Beta vulgaris cicla*)	10	<2	13	41	13
Cherry (*Prunus cerasus*)	19	33	145	352	82
Chives (*Allium schoenoprasum*)	105	<2	184	4090	493
Cucumber (*Cucumis sativus*)	9	<2	13	56	17
Dill (*Anethum graveolens*)	21	<2	18	87	23
Fennel (*Foeniculum vulgaris*)	1	<2	2	2	0
Goutweed (*Aegopodium podagraria*)	2	229	298	367	69
Kale (*Brassica acephala*)	8	<2	14	36	14
Kohlrabi (*Brassica gongyloides*)	2	<2	39	75	37
Leek (*Allium porrum*)	9	<2	94	430	129
Lettuce (*Lactuca sativa*)	75	<2	13	143	21
Lovage (*Levisticum officinale*)	5	<2	22	68	25
Mint (*Mentha viridis*)	2	136	195	254	59
Nettle (*Urtica dioica*)	15	13	418	4460	1100
Onion (*Allium cepa*)	11	<2	5	24	7
Parsley (*Petroselinum crispum*)	55	<2	735	7720	1420
Pea (*Pisum sativum*)	4	<2	10	21	8
Plum (*Prunus domestica*)	3	<2	20	29	12
Potato (*Solanum tuberosum*)	159	<2	20	1570	124
Radish (*Raphanus sativus*)	20	<2	7	27	8
Rhubarb (*Rheum rhaponticum*)	30	<2	16	183	32
Spinach (*Spinacia oleracea*)	10	<2	12	43	12
Squash (*Cucurbita pepo*)	3	<2	7	18	8
Swede (*Brassica napus*)	28	<2	8	50	11
Tomato (*Solanum lycopersicum*)	7	<2	4	13	4
White cabbage (*Brassica oleracea*)	23	<2	13	165	33
TOTAL	741				

Table 15. Content of ^{137}Cs (Bq/kg wet) in berries.

SPECIES	NBR	MIN	AVG	MAX	STD
Arctic bramble *(Rubus arcticus)*	9	29	128	315	109
Bilberry *(Vaccinium myrtillus)*	367	<2	150	1130	170
Blackberry *(Rubus fruticosus)*	1	64	64	64	0
Black currant *(Ribes nigrum)*	94	<2	50	176	38
Cloudberry *(Rubus chamaemorus)*	446	<2	362	2750	385
Cowberry *(Vaccinium vitis-idaea)*	343	<2	187	904	187
Cranberry *(Vaccinium oxicoccus)*	2	281	304	327	23
Gooseberry *(Ribes uva-crispa)*	26	<2	38	117	29
Raspberry *(Rubus idaeus)*	198	<2	115	945	123
Red currant *(Ribes rubrum)*	55	<2	36	149	29
Rowanberry *(Sorbus intermedius)*	3	<2	69	190	86
Strawberry *(Fragaria ananassa)*	90	<2	32	140	35
Wild strawberry *(Fragaria vesca)*	37	<2	141	708	171
TOTAL	1671				

Table 16. Content of ^{137}Cs (Bq/kg wet) in cloudberry in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AC	73	<2	231	1060	225
BD	10	5	61	216	56
C	10	76	406	2000	541
S	9	9	82	175	51
U	11	41	231	973	259
W	26	6	83	183	41
X	81	<2	447	1820	425
Y	140	16	575	2750	447
Z	82	<2	209	678	149
TOTAL	446				

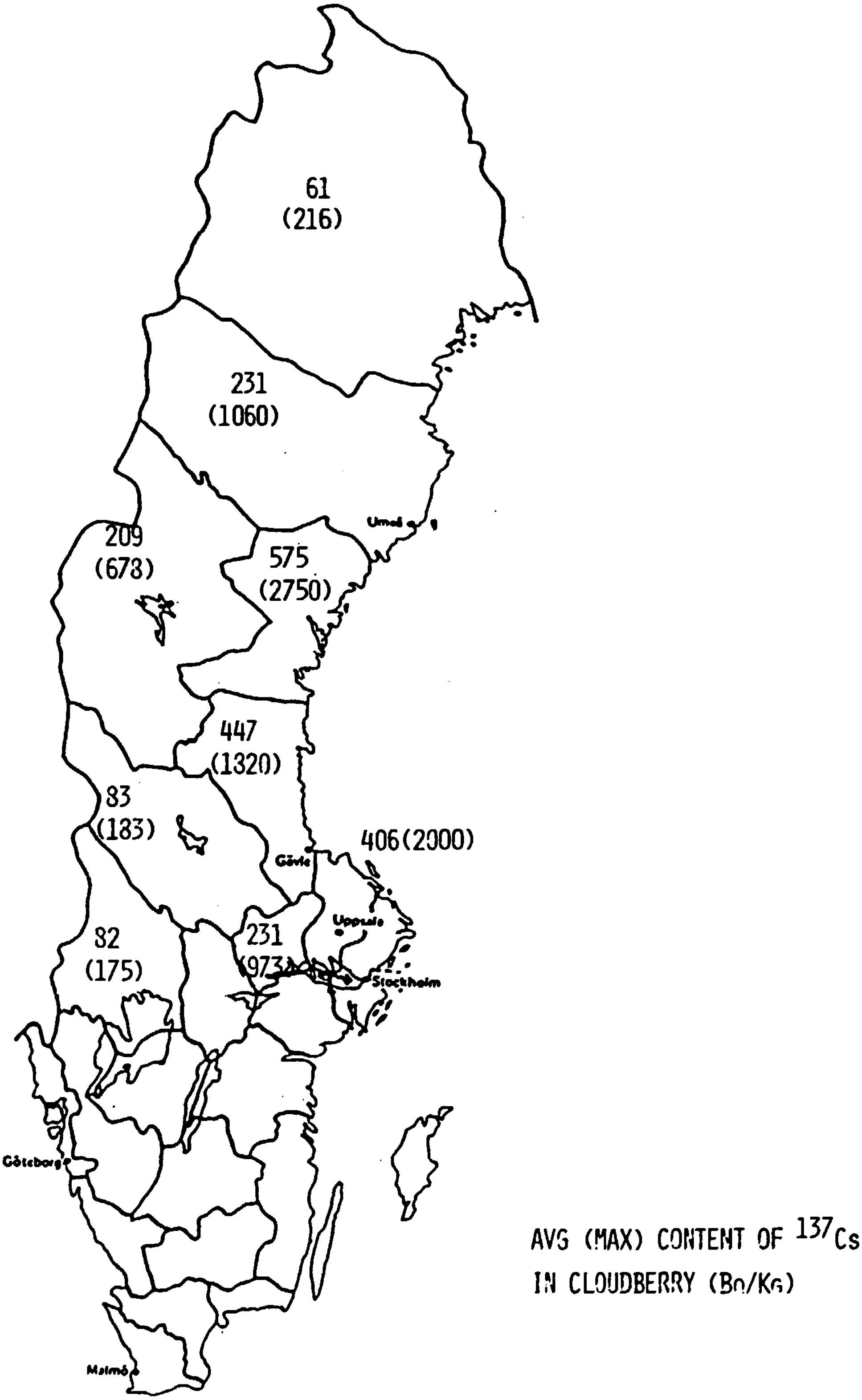

Fig. 14. Geographical distribution of ^{137}Cs in cloudberry.

Mushrooms

Also among mushrooms the geographical distribution of the uptake followed the deposition pattern: Table 17 and Fig. 15 show the levels of ^{137}Cs in different regions.

Table 17. Content of ^{137}Cs (Bq/kg wet) in mushrooms in different counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	9	<2	26	81	30
AC	10	<2	925	4980	1430
BD	2	<2	49	96	47
C	122	<2	761	13000	1470
D	13	17	168	723	188
E	3	<2	51	86	36
S	2	10	217	423	207
T	2	44	45	46	1
U	55	<2	622	5610	985
W	18	<2	69	205	50
X	102	14	655	9700	1220
Y	145	<2	1090	11300	1980
Z	11	25	410	2460	675
TOTAL	495				

As reported by others,[29] the Cs-content in some mushrooms was high and the ratio $^{134}Cs/^{137}Cs$ diverged unusually widely from the other food samples investigated. The ratio, especially with low Cs-values, was quite irregular and in several cases ^{134}Cs was totally absent or present in much lower concentration than expected (Figs. 16 and 17). This led to the conclusion that "old" fallout (^{137}Cs) was involved in the uptake, especially in forest conditions where the "umbrella effect" of the trees made the deposition very unhomogeneous.

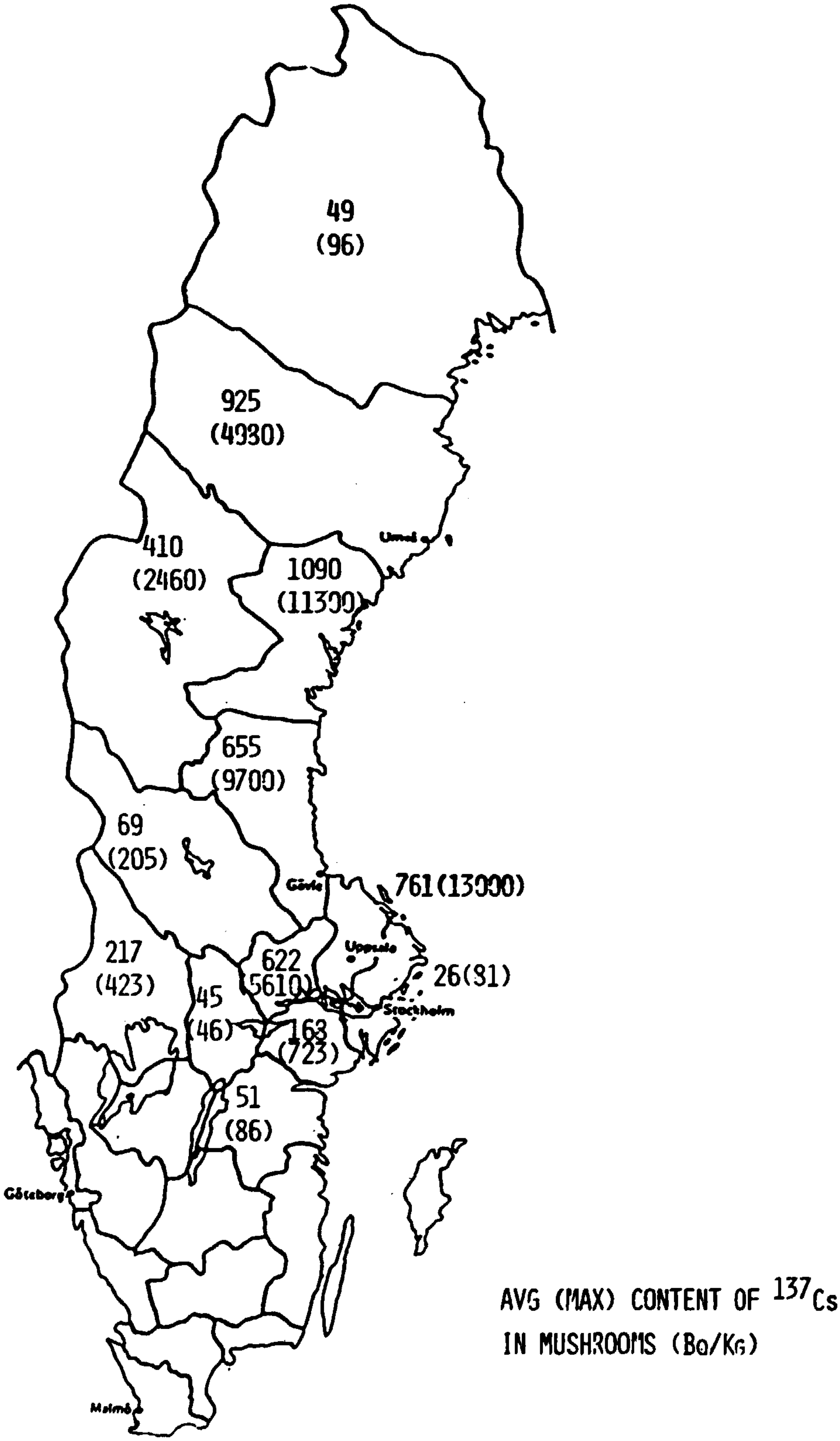

Fig. 15. Geographical distribution of ^{137}Cs in mushrooms.

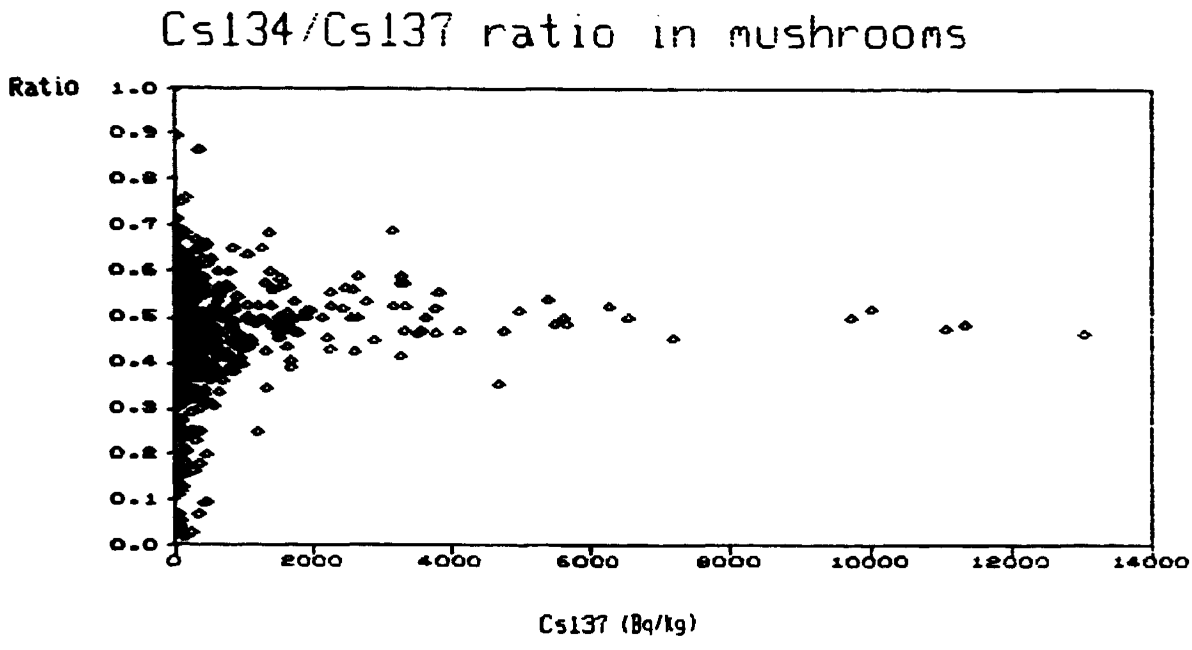

Fig. 16. Distribution of $^{134}Cs/^{137}Cs$ ratios in mushrooms with different ^{137}Cs-contents.

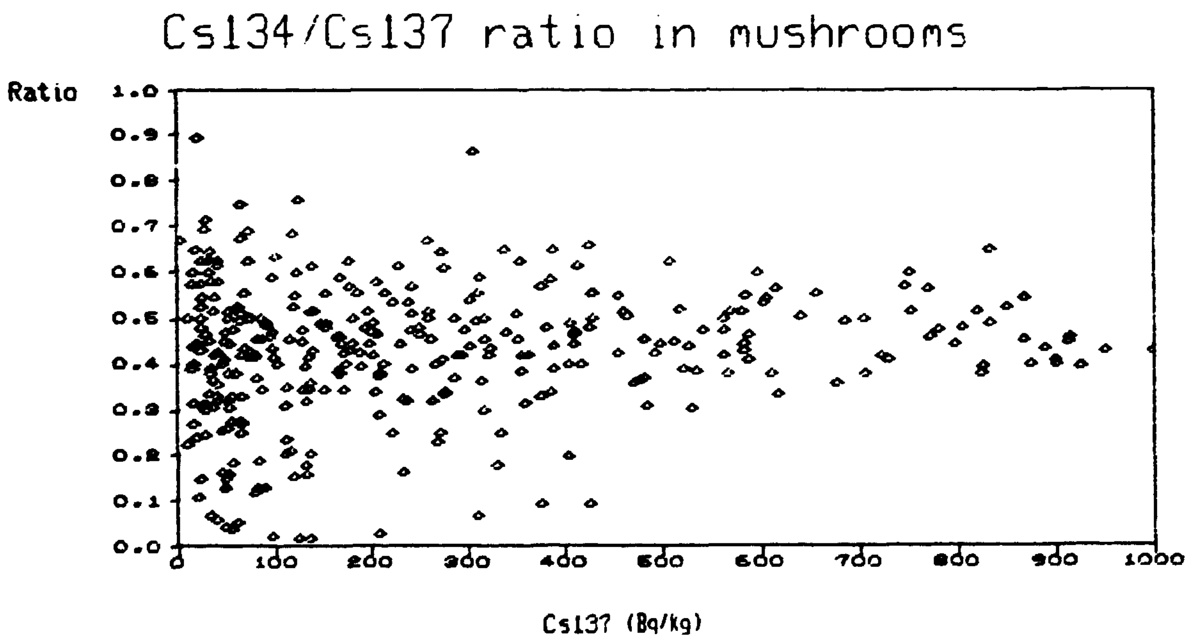

Fig. 17. Distribution of $^{134}Cs/^{137}Cs$ ratios in mushrooms with ^{137}Cs-contents < 1000 Bq/kg.

Cs-uptake in mushrooms varied between species (Table 18 and Fig. 18) and maximum and mean Cs-values showed a more regular pattern than in fish (Fig. 19). High values were recorded in mushrooms which grow on sandy soils, where ^{137}Cs is more mobile and readily absorbed.[40] Generally, the uptake of ^{137}Cs in mushrooms depends on a very complex system of parameters, strongly correlated to the physical

Table 18. Content of ^{137}Cs (Bq/kg wet) in different mushroom species.

SPECIES	NBR	MIN	AVG	MAX	STD
Agaricus arvensis	4	<2	19	51	20
Agaricus spp.	12	<2	987	6280	1890
Albatrellus ovinus	17	13	101	260	76
Boletus edulis	28	<2	102	1140	215
Boletus spp.	22	9	290	1020	326
Cantharellus cibarius	197	<2	496	5610	771
Cantharellus tubaeformis	28	29	973	3780	1080
Craterellus lutescens	11	409	1510	3170	899
Gyromitra esculenta	18	<2	239	1030	268
Hydnum repandum	12	88	867	4140	1160
Hydnum spp.	9	134	357	901	222
Hygrophorus spp.	2	2890	7960	13000	5070
Lactarius deterrimus	6	208	592	1330	365
Lactarius spp.	8	338	2600	5490	1710
Leccinum scabrum	10	15	157	413	143
Polyporus spp.	4	32	80	198	69
Rozites caperata	18	30	2570	11300	3290
Russula decolorans	6	292	2970	11100	3760
Russula spp.	30	<2	673	3350	848
Suillus luteus	6	22	140	361	107
Suillus variegatus	20	26	2420	9990	270
Tricholoma spp.	2	<2	6	10	4
TOTAL	470				

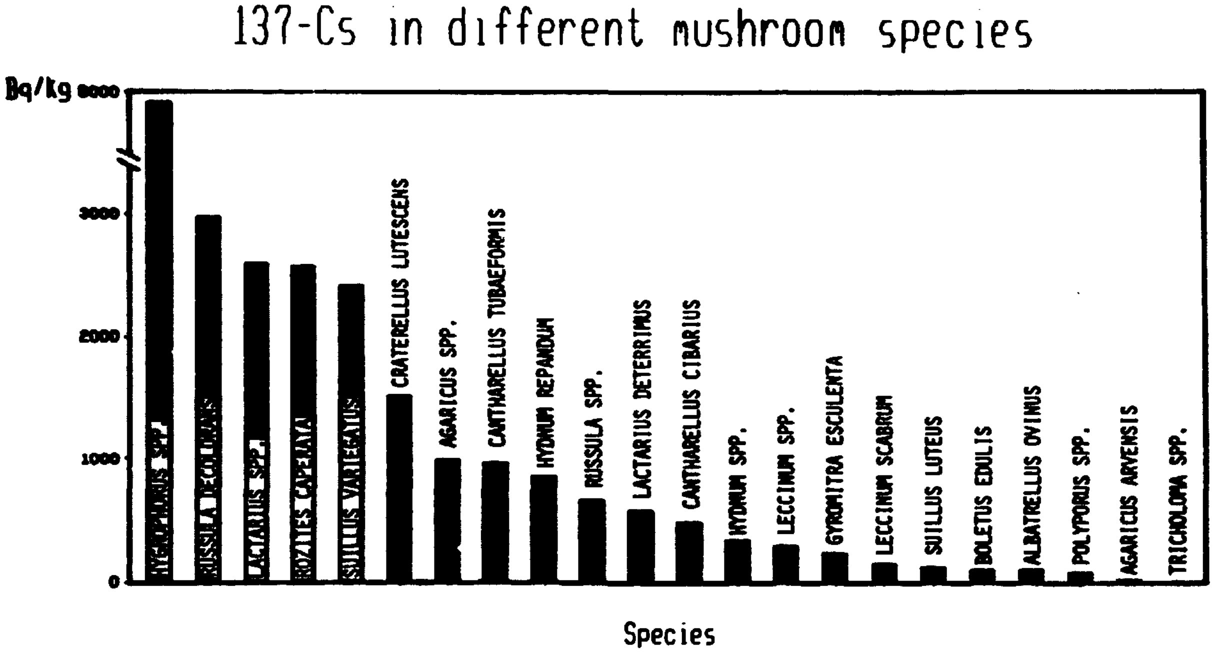

Fig. 18. Mean ^{137}Cs-concentration in different mushroom species.

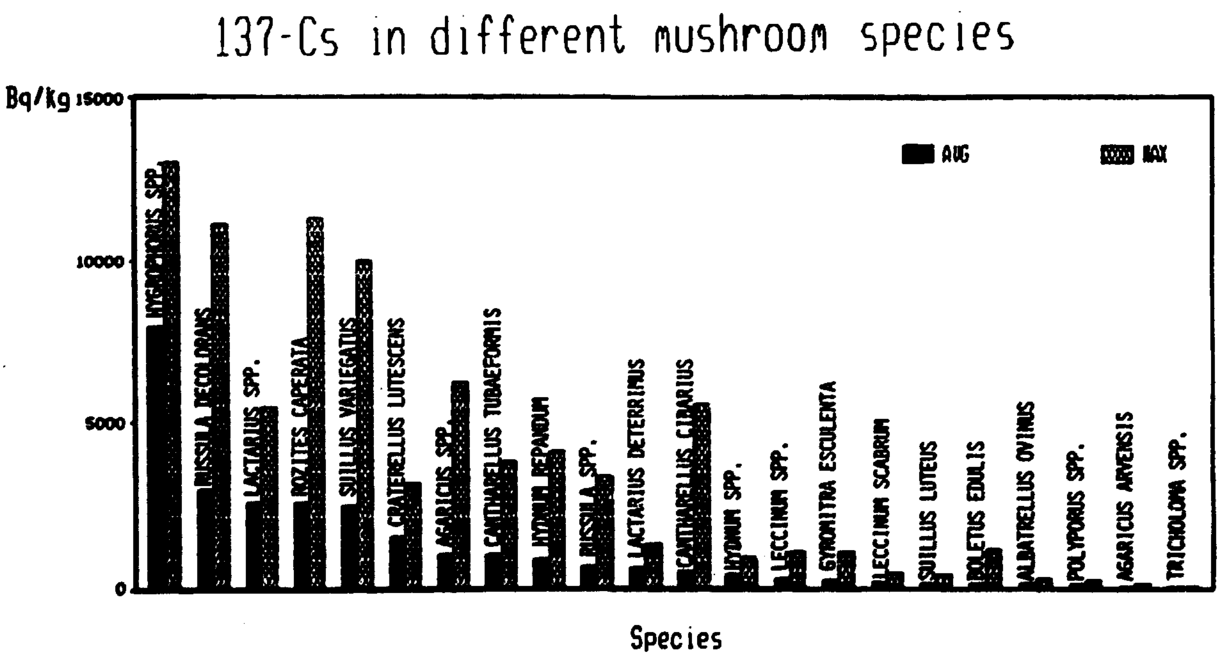

Fig. 19. Comparison between average and maximum ^{137}Cs-concentrations in different mushroom species.

and chemical properties of the soil and particularly to potassium and clay content.[41] High concentrations of ^{137}Cs usually reflect high $^{137}Cs/K$ ratios relative to K-poor substrates. However, it is not clear to what extent ^{137}Cs-content in mushrooms depends on these factors or on contamination from deposited particulates. As fungi bodies have high surface areas to dry weight ratios, they are subject to the influence of surface contamination to a larger extent than other forms of vegetation.[42]

Several other factors, like mineral and organic status of the soil, water availability, re-translocation of nutrients to mycelium (as in old fungi) and substrate conformation might have influenced the results. The age of the fruit bodies also seems to affect the uptake, as older mushrooms absorbed more water with more ^{137}Cs than younger ones.[43]

Experiments aimed to reduce the Cs-concentration in mushrooms were carried out at the National Food Administration and showed that cooking achieved an 80% reduction,[44] confirming previously obtained results.[41]

Honey

The concentration of ^{137}Cs in honey was monitored in several regions and found to be low (Table 19, Fig. 20).

Table 19. Content of ^{137}Cs (Bq/kg wet) in honey indifferent counties.

COUNTY	NBR	MIN	AVG	MAX	STD
AB	4	14	24	34	8
C	10	<2	62	154	49
U	9	18	78	205	54
W	3	<2	45	130	60
X	14	<2	153	482	162
Y	12	23	90	246	71
TOTAL	52				

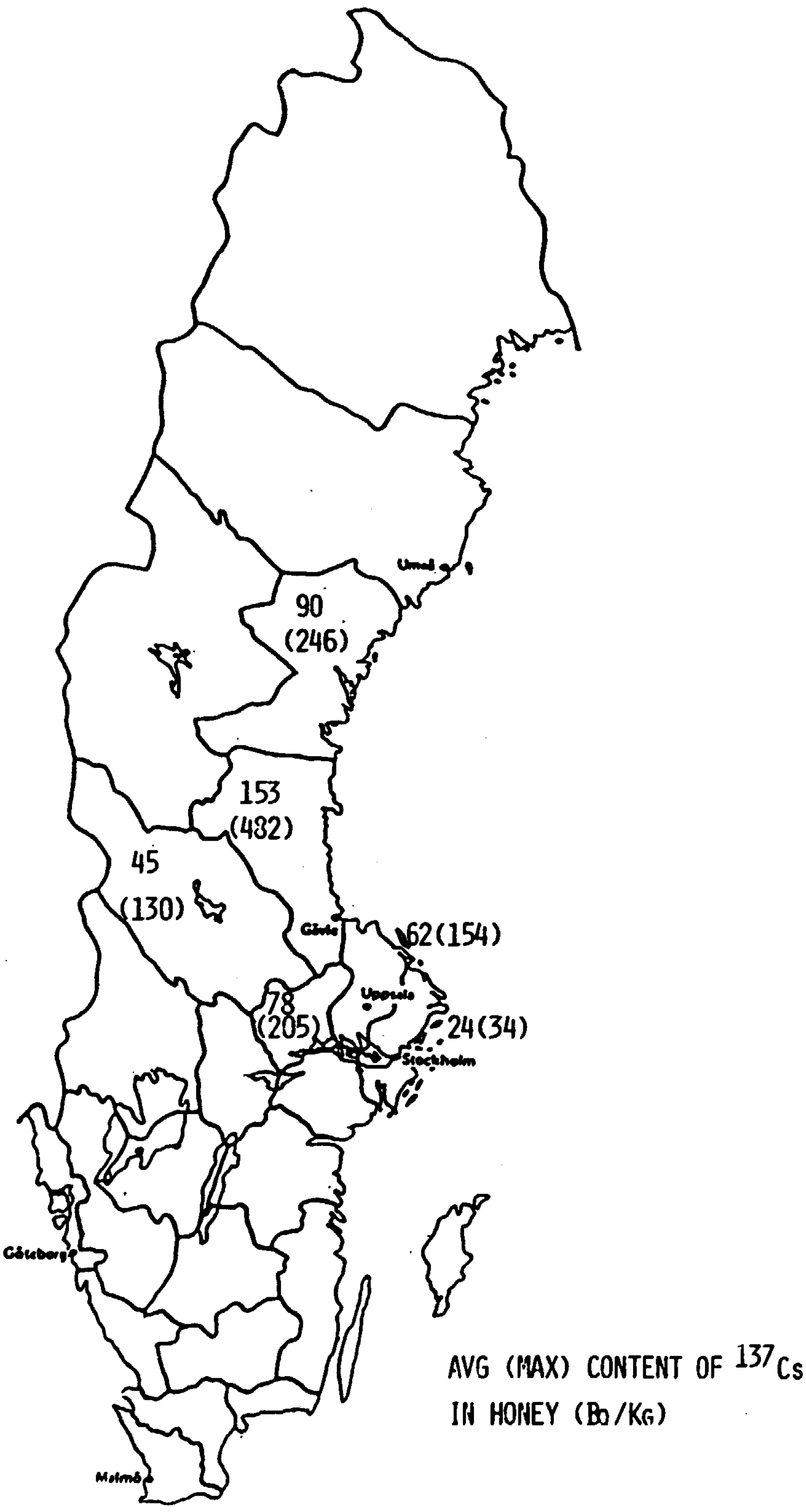

Fig. 20 Geographical distribution of ^{137}Cs in honey.

A slight increase was observed at the end of the summer, probably due to the contribution of two flowers, willow herb *(Epilobium angustifolium)* and heather *(Calluna vulgaris)*.[45] Activity in pollen was also detected: the diagram in Fig. 21 shows the Cs-content in pollen collected immediately after the radioactive fallout at the Bee Division of the Department of Animal Nutrition and Management in Uppsalo. The honey produced by the same bee-colony was analyzed after about one month, showing that the ^{137}Cs-concentration was very low (73 Bq/kg).

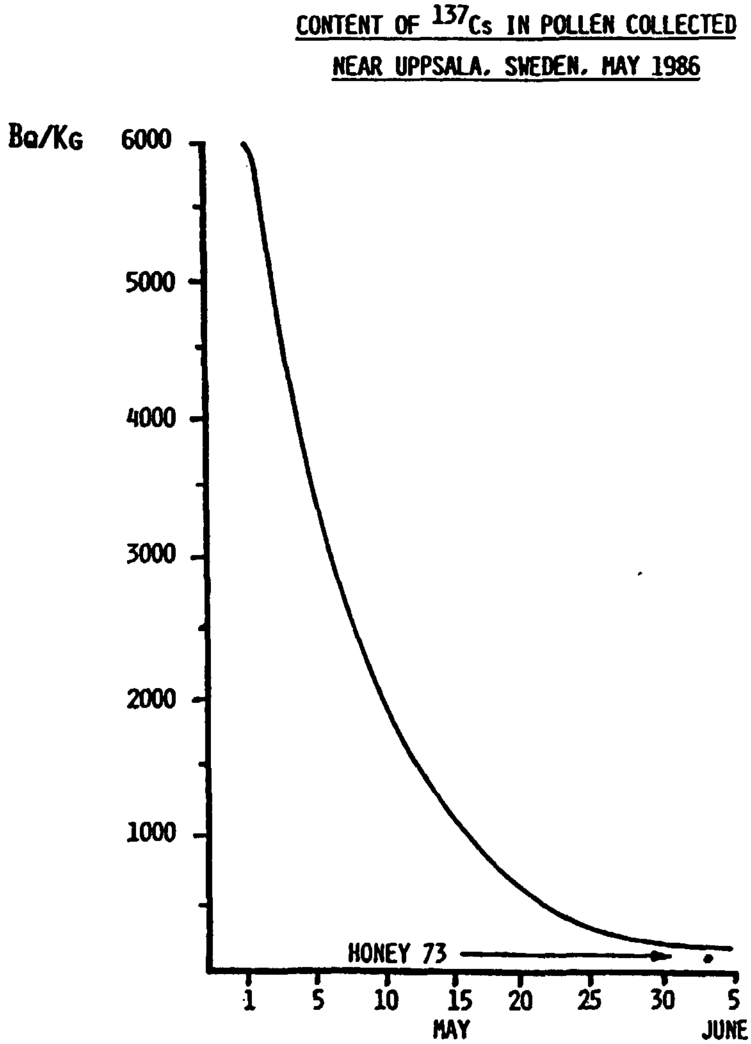

Fig. 21. Content of ^{137}Cs in pollen collected in Uppsala after the Chernobyl-fallout.

CONCLUSIONS

The temporal distribution of maximum measured values for several foodstuffs is shown in Fig. 22. It can be observed these values are strongly related to seasonal parameters and accumulation factors as well.

The ecological chain as a whole is a self-affecting system and the Cs-levels in some links appear to be influenced by feed-back phenomena. This issue is established in the case of reindeer and lichens[46] but also the high ^{137}Cs concentration sometimes found in other game animals might be correlated to elements in their diet with elevated Cs-contents, like mushrooms.[47] On the other hand, many complex and not easily predicted factors may influence the behaviour of ^{137}Cs in the environment[48] or even lead to unexpected conclusions.[49]

An interpretation of the results obtained and an understanding of certain functional processes is desirable, while not always readily achieved. Nearly every component of an ecological system has some influence upon the fate of radiocontaminants introduced into the system.

The major problems induced in some parts of the ecosystem, like reindeer, mushrooms and closed water fish, are expected to continue for several years. Experiments aimed at studying specific issues have been started in Sweden by several research groups and will be essential for a solution of various problems. However, many of the questions that have arisen will probably find better answers with wide, long-term investigations and, most important, multi-disciplinary efforts.

The transport and long-term behaviour of radionuclides in the environment under Swedish field conditions has been studied for many years by this Department, as is reflected by the number of publications on the subject. Obviously, much is still to be learned, but to-day's knowledge can be applied in obtaining better understanding of the ecological system in this stressed situation.

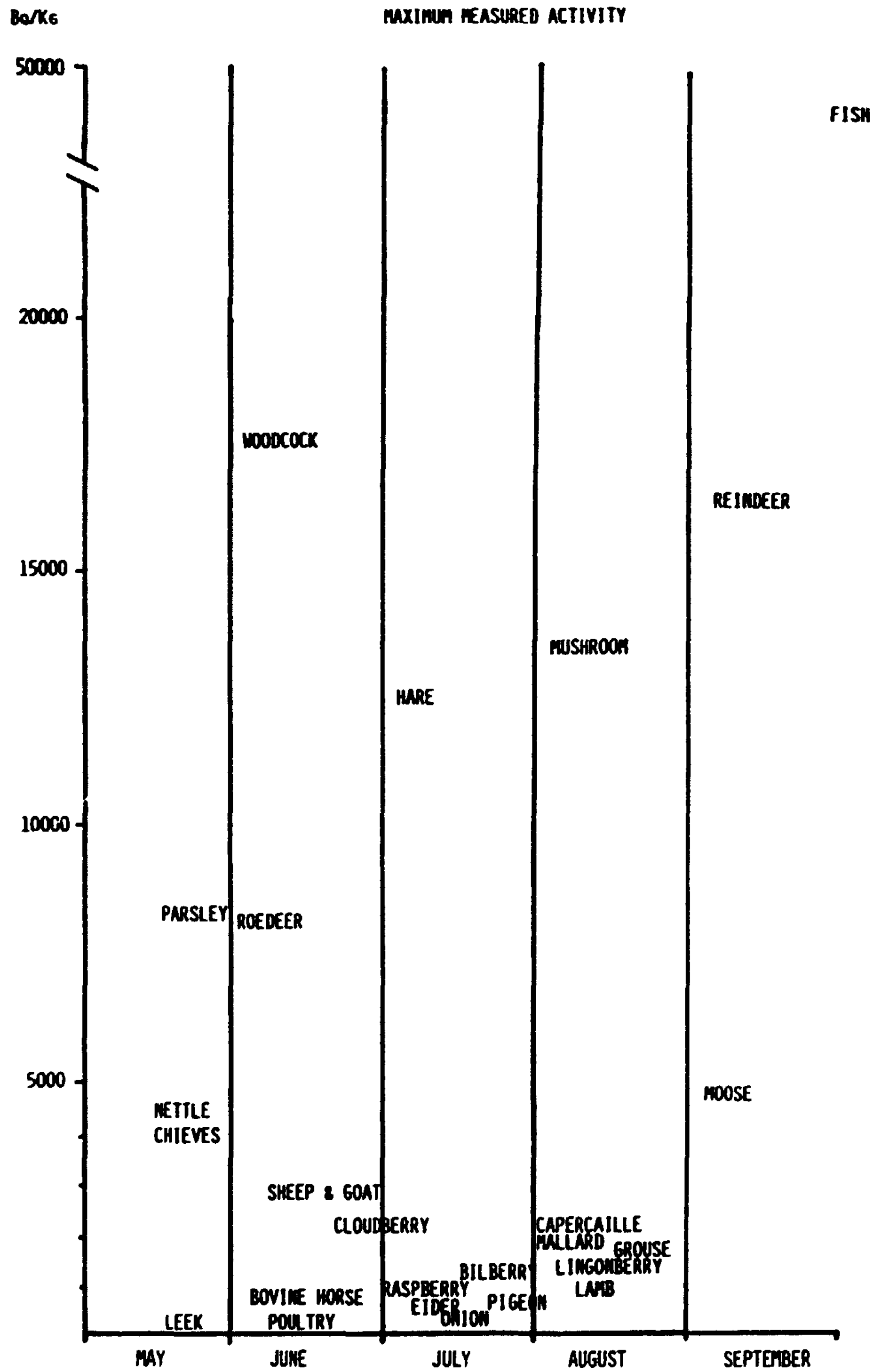

Fig. 22. Temporal distribution of maximum measured ^{137}Cs-values for different foodstuffs.

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