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ABSTRACT

The Chernobyl accident raised the deposition levels of radioactive substances in Finland. Fish were affected by radioactive substances in watersheds. Extensive study of areal and temporal changes in the radioactivity of freshwater fish was started soon after the accident.

The aim of the study was to obtain new data on a situation involving fresh deposition and to estimate the importance of freshwater fish as a source of radiocesium for consumers. Attention was also paid to various factors affecting the radioactivity of fish.

Samples were taken from about 200 lakes. In all, about 600 samples were analysed gammaspectrometrically. A few samples were also analysed radiochemically for beta-emitting ^{89}Sr and ^{90}Sr. The samples contained about ten different species of fish.

The highest concentrations of radiocesium in fish were found in the areas of highest radioactive deposition in Finland. In areas with the same level of ^{137}Cs deposition, concentrations in fish depended on the size of the lake: the smaller the area of the lake in which the fish were caught the higher the concentration. Of the fish species studied, perches had the highest concentrations of radiocesium.

Intake estimations were based on the average concentrations, weighted for catches, in each drainage area and in the whole country, and on the average consumption of freshwater fish. In Finland, the average intake of ^{137}Cs via freshwater fish in May-December 1986 was about 1200 Bq. The values obtained for different drainage basins varied from about 160 to 3400 Bq.

CONTENTS

1 INTRODUCTION

The accident at Chernobyl raised the deposition levels of radioactive substances in Finland, but areal deposition was uneven [1,14]. Drainage basins (the statistical fishery areas) 4 and 5 (Figs. 1 - 2) were the most severely contaminated by the Chernobyl fallout, while a large part of drainage basin 3, which is the most important for freshwater fishing in Finland, was only slightly contaminated. The average deposition of ^{137}Cs in the major part of coastal drainage basins 1, 2 and 6, which are of minor importance in freshwater fishing in Finland, was lower than 22 kBq m^{-2} .

Besides by the analyses of deposition and the measurements of external dose rates, distribution of radionuclides in various watersheds was studied by analyses of surface water [13]. The highest concentrations of radioactive cesium in surface water were detected in drainage basins 5 in 1986 [13]. The maximum content of radiocesium in surface water coincided with the period of elevated biological activity in aquatic food chains. In addition, the most important fishing season was then just about to start. Extensive monitoring of the radioactivity of fresh water fish was started in Finland soon after the accident.

On one hand, this study was undertaken to monitor fish as a food, that is, to estimate the importance of freshwater fish as a source of radiocesium to consumers and, on the other hand, to determine the significance of various factors to changes in the radiocesium concentrations in fish in fresh fallout situation.

Concerning the dependence of the radioactivity in fish on the size of the lakes, the sizes of Finnish lakes were considered. In Finland, fresh water (lakes and rivers) covers an area of 33 600 km^2, which is 9.9 % of the total area of the country. The number of lakes is estimated to be about 56 000. They are most abundant in central and eastern Finland; in places about 25 % of the total area is water. Finnish lakes are shallow, the average depth being about 7 m. The tötal volume of the lakes is about 230 km^3. The following figures give the size distribution of Finnish lakes:

Surface area	Number of lakes
$\geq$ 200 km^2	17
$\geq$ 100 km^2	37
$\geq$ 50 km^2	81
$\geq$ 1 km^2	2 589
$\geq$ 1 ha	56 000

There are almost 132 000 very small lakes or ponds with an average area of 5 a - 1 ha [2,3].

Attention was also paid to the differences in radioactivity between various fish species and various fish groups with different feeding habits, as well as between different sized fishes of one species. The characteristics of the lakes, such as surface area, water volume, abundance of nutrients, etc, and the characteristics of the catchment area, also affect the contamination of fish by radioactive substances, but not all of these are discussed further in this paper. The speed of excretion of ^{137}Cs in fish plays an important role, affecting on one hand the level to which the activity concentrations will raise and on the other hand, how rapidly the activity concentrations of fish decrease, when activity concentrations in food have started to lower [5].

Results reported here give figures for the average intake of ^{137}Cs via freshwater fish and thus form a basis for estimating radiation doses to man via freshwater fish in various deposition areas in Finland and in the country as a whole. Doses will be assessed in the Annual Report for 1986 [18].

2 MATERIAL AND METHODS

2.1 Sampling

The main purpose of the sampling was to clarify the effect of the Chernobyl accident on the radioactivity of freshwater fish. Therefore, sampling concentrated on the areas of highest deposition, but the entire country was covered in the monitoring programme.

The monitoring programme included samples taken from Finland's six largest lakes and from the other large lakes of great importance for freshwater fishing (Fig. 2). In order to locate the highest possible concentrations of ^{137}Cs in fish, samples were also taken from small lakes (surface area less than 1 km^2) mainly in the area of highest deposition (fallout categories 4 and 5 in Fig. 1.).

The total numbers of fish samples analysed and the number of lakes from which fish samples were taken in the various provinces in 1986:

Province	Number of fish samples analysed	Number of lakes
Häme	184	40
Central Finland	88	22
Kuopio	49	15
Kymi	21	8
Lapland	73	42
Mikkeli	35	13
Oulu	65	31
North Karelia	11	3
Turku and Pori	39	19
Uusimaa	18	8
Vaasa	9	5

The fish species chosen for the programme were those most commonly used for food: perch, pike, vendace, bream, burbot, roach, white fish and pike-perch. Some samples of rudd, silver bream, smelt, eel, and cultivated rainbow trout were also included. Of these species, perch, pike and vendace each account for more than 20 % of the total catch of freshwater fish in Finland. The fishes were the normal size for edible fish and represent typical catches. The samples also included very small vendace and perch, which are also eaten in Finland. The sampling times were to some extent affected by seasonal changes in fishing for different species.

Samples were obtained from several sources; many private fishermen, the Finnish Game and Fisheries Research Institute and the University of Jyväskylä assisted with the collection of samples.

2.2 Sample treatment

Samples were received by STUK (Finnish Centre for Radiation and Nuclear Safety) and preserved deep-frozen until further treatment.

The fish were cleaned and gutted as normally in the kitchen. Big fishes were cut into fillets, and heads, entrails, scales or skin, fins, backbone and other big bones were removed. Only the heads and entrails were removed from small perches, vendaces, roaches and other small fishes. Thus the parts taken for analysis represented edible fish. Some of the samples, consisting of a large number of fishes of different size, were subsampled according to the size of the fish.

2.3. Analyses

2.3.1 Gamma-spectrometric analyses

The cleaned samples were cut into small pieces and packed into Marinelli beakers about 560 ml in volume. If only a small amount of sample was available, a smaller cylindrical geometry (volume 30 ml) was used.

Gammaspectrometric analyses were performed using either lithium drifted or high purity detectors with relative efficiencies of between 15 % and 39 %. The measuring times varied between 15 minutes and about one hour. The activity concentrations of the samples were calculated using the computer programme GAMMA-83 [15,16]. Radiocesium concentrations were in all the samples high above the detection limit.

2.3.2 Radiochemical analyses

After the gammaspectrometric analyses the samples were dried at 105°C and ashed at 450°C. The ashed samples were dissolved, and radiostrontium was separated radiochemically using the nitric acid precipitation method [4]. After separation of strontium, ^{89}Sr and ^{90}Sr were measured together as carbonate. After a two-week ingrowth period, ^{90}Y, the daughter of ^{90}Sr, was precipitated as yttrium-oxalate and measured. Measurements were made with a low-background gas flow beta-counter.

2.4 Data treatment

The fish species studied were divided into three groups based on feeding habits:

- Predators: pike, pike-perch, burbot
- Non-predators or benthic feeders: vendace, bream, roach and other roach-related fish
- Part predators and part non-predators (intermediate group): perch, white fish

Perch, which is the most important fish in freshwater fishing, is the dominanting species in the third group.

The lakes in this study were divided into four size classes. The first class comprised the six largest lakes: Saimaa, Päijänne, Kallavesi, Inarinjärvi, Oulujärvi and Pielinen (Fig.2). The surface area of each lake is more than 890 km² (group 1). Of these, Saimaa, Inarinjärvi, Pielinen and Oulujärvi are in the area with a ^{137}Cs deposition of 0 to 4.3 kBq m^{-2}. Päijänne is in the area of higher ^{137}Cs deposition (10.2 - 67 kBq m^{-2}) (Figs. 1 and 2).

The other lakes were classified by area using maps at a scale of 1: 200 000. The lower size limit of the second lake class was 20 km^2. However, most of the lakes in this class (group 2) had an area of more than 100 km^2. The number of lakes in this class was 27.

The third class comprised lakes with an area of 1 to 20 km^2. There were 33 of these in all in this study.

The lakes with a surface area of less than 1 km^2 constituted the fourth class. This class consisted mainly of oligotrophic lakes, which were the main target of efforts to find the highest concentrations of ^{137}Cs in freshwater fish. Although of minor importance in terms of fishing, this class exhibits the maximum radionuclide contents in fish. There were 71 lakes in this class in the present study.

2.5. Calculations

The distribution of catches of freshwater fish in different drainage basins was calculated from the statistics [6], taking into account both recreation and subsistence fishing and professional fishing. The division of fishes into three groups was based on their feeding habits. The catches in each group in each drainage basin were calculated. The sum of the catches of each group is the total catch for the drainage basin.

For intake estimation the countrywide average concentration of ^{137}Cs in freshwater fish was calculated. The average concentrations of ^{137}Cs for each three fish groups were used in each drainage basin. In addition, in drainage basins 3, 4, 5 and 7 the average concentrations of ^{137}Cs for the three fish groups were calculated separately for two lake classes: those with a surface area of more than 20 km^2 and those with a surface area of less than 20 km^2. Lakes with a surface area of less than 20 km^2 in the four aforementioned drainage basins, were assumed to account for 10 % of the total catch in the drainage basins in question.

The intake of ^{137}Cs via freshwater fish (I) in June-December 1986 was calculated using the following equation:

$$I = \frac{1}{M} \times C \times T \sum_{i=1}^{8} \sum_{j=1}^{3} A_{i,j} \times m_{i,j}$$

where M = total annual catch of freshwater fish [8] (kg)

C = daily average consumption of cleaned fish per person ($kg\ d^{-1}$)

T = time period (d)

$A_{i,j}$ = activity concentration of ^{137}Cs in fish group j in fishing area i ($Bq\ kg^{-1}$)

$m_{i,j}$ = catch of fish in fish group j in fishing area i [8] (kg)

The intake estimation in May was based on the low content of ^{137}Cs in fish before the fallout in spring 1986 [17] and on the daily average consumption.

RESULTS

The radioactive substances, detected by gammaspectrometric measurements on freshwater fish, are the two cesium isotopes ^{134}Cs and ^{137}Cs. The ratio of ^{134}Cs to ^{137}Cs was about 0.5 in June-July 1986. The ratio then gradually decreased as a result of the shorter half life of ^{134}Cs. Therefore, although only the concentrations of ^{137}Cs are dealt with in this study, concentrations of ^{134}Cs also exist, being about half of those of ^{137}Cs. In addition, two strontium isotopes, ^{89}Sr and ^{90}Sr, have been detected in the radiochemical analyses of fish carried out to date.

The effect of Chernobyl fallout on the concentrations of radiocesium in fish was first noted in June 1986 although the accident occurred on April 26. There are only a few results, all of them low, for May, although traces of ^{134}Cs were detected even then. Concentrations of radioactive cesium in fish increased sharply in July - September 1986 in drainage areas 4 and 5, which were the most severely affected by Chernobyl deposition in Finland (Fig. 4). The increase was highest in the concentrations in perches.

The levels of concentrations of ^{137}Cs in fish show the dependence on the deposited ^{137}Cs in the area, being highest in deposition areas 4 and 5 and lowest in deposition area 1 (Figs. 5 - 6). In addition, concentrations of ^{137}Cs in a certain fish species increase, when the surface areas of the lakes decrease in the same deposition area. This is seen most clearly in perch. The same tendency is also apparent, albeit not so clearly, in the data on other fish species (Fig. 5).

An increase in ^{137}Cs concentrations is also apparent in the three fish groups, predators, benthic feeders and the intermediate group, when the surface areas of the lakes decrease. This is most obvious in the intermediate group, because perch is the dominant fish is this group. On the whole, the intermediate group has the highest ^{137}Cs concentrations and the group with predators the lowest. Some exceptions were found in cases when number of samples was small (Fig. 6).

There are clear differences between various drainage basins in the ^{137}Cs concentrations in individual fish species and in the three fish groups (Figs. 7 - 8). Concentrations are highest in drainage basins 4 and 5 and lowest in drainage basin 8 (Figs. 7 - 8). A more detailed discussion of the studies of food chains in Finnish Lapland is presented in another report [11].

In an area with the same level of ^{137}Cs deposition, concentrations of radiocesium in fish and fish groups were roughly inversely proportional to the areas of the lakes (Figs. 5 - 6). With some exceptions, the same kind of dependence was also evident in the drainage basins (Figs. 7 - 8).

Concentrations of ^{137}Cs were lowest in predators and highest in the intermediate group also in the eight drainage basins (Fig. 8). Perches had the highest concentrations of ^{137}Cs (Fig. 7).

The average concentrations of ^{137}Cs in fish from individual lakes of classes 1 - 3, which are listed by province, are given in Tables I- III. The highest average concentrations of ^{137}Cs were detected in the provinces of Häme and Central Finland. The highest average concentrations of ^{137}Cs in fishes from lake class 1 were somewhat below 2000 Bq kg^{-1}, those of lake class 2 somewhat above 3000 Bq kg^{-1} and those of lake class 3 above 11 000 Bq kg^{-1}. Variations in the level of ^{137}Cs in individual fish species from lakes of different size within a province is large. (Tables I - III). The average concentrations of ^{137}Cs in individual fish species from lake class 4 are given by province in Table IV. Concentrations of ^{137}Cs were highest in the province of Häme (Table IV).

The contents of radioactive cesium were dependent on the size of the fishes. The smaller the fishes the higher were the concentrations of radioactive cesium within one fish species, caught at the same time, in one particular lake in the main deposition area (fallout categories 2 - 5 in Fig. 1). This applied even more generally to perches of different size caught in lake class 4 in the main deposition area (Fig. 9). The differences between the size groups of fishes, S (small) and M (medium), are not great in Fig. 9. This is because the samples in group M also contained some small fishes that were not separated from the sample and therefore raised the average of the group.

The average concentration of ^{137}Cs in cultured rainbow trout was 40 Bq kg^{-1} . Twelve samples of rainbow trout from the provinces of Häme, Kuopio, Mikkeli, and Turku and Pori were analysed. The range was 0.5 - 230 Bq kg^{-1} .

Concentrations of ^{90}Sr in fish analysed to date from six lakes varied from 0.30 to 17 Bq kg^{-1} fresh weight. The average concentration of ^{90}Sr in perch and vendace, which were analysed with bones, was 10 Bq kg^{-1} fresh weight and that of pike, pike-perch, white fish and rainbow trout 0.6 Bq kg^{-1} . Concentrations of the shorter-lived ^{89}Sr ($T_{1/2}$ 50.5 days) varied between 0.1 and 20 Bq kg^{-1} fresh weight in July-August (Table V).

The most important area of freshwater fishing in Finland is drainage basin 3, which accounts for nearly 40 % of the total catch. Drainage basins 4 and 5 are the next most important, representing 19 % and 12 % of the total catch, respectively. Coastal areas 1, 2 and 6 account for 3 - 5 % of the total catch in freshwater fishing (Fig. 10).

The relatively low concentrations of ^{137}Cs in fishes in area 3 indicate that this area accounted for only about 13 % of the intake of ^{137}Cs via freshwater fish. Drainage basins 4 and 5 accounted for the highest intake of ^{137}Cs, being about 39 % and 35 % of the intake, respectively. The proportion of the intake of ^{137}Cs in coastal drainage basins 1, 2 and 6 was the same as their proportion of catches. Areas 7 and 8 accounted for only a small proportion of ^{137}Cs intake via fish, because the concentrations of radioactive cesium there are low [11] (Fig. 11).

The average intake of ^{137}Cs via freshwater fish varied from about 160 to 3400 Bq in the various drainage basins in May-December 1986. This was calculated using an average consumption of 4 kg a^{-1} of freshwater fish per person. The intake was highest in drainage basins 5 and 4, where it was 3400 and 2400 Bq a^{-1}, respectively (Fig.12).

The average intake of ^{137}Cs from freshwater fish countrywide was about 1200 Bq in May-December 1986. The countrywide average concentration in fish, weighted for catches, 500 Bq kg^{-1}, and the average consumption, 4 kg a^{-1} cleaned fish, were used in the calculation.

4 DISCUSSION

Concentrations of radioactive cesium in fish increased in the whole country as a result of the Chernobyl accident. Before the accident the concentrations had reached low equilibrium values after the fallout period in the 1960s. The concentrations of ^{137}Cs in freshwater fish in 1982, when the latest study before the accident was done, varied from 2.1 to 64 Bq kg^{-1} fresh weight, in various lakes and fish species [9,17].

The amount of radioactive deposition in any area was the most important factor determining the level of radioactive cesium concentrations in fishes after the Chernobyl accident. In addition, many environmental factors affect the transport of radioactive substances from an aquatic environment into fish. These may alter the situation, even in areas with the same amount of deposited radioactive substances. The same factors were thoroughly studied also in Finland in 1960s [5,6,7]. One of these factors, ascertained by earlier studies as having a marked effect on contamination of fishes by radioactive substances, is the amount of nutrients in water. This factor is not dealt with here. The results of the earlier studies cannot be applied as such to the Chernobyl deposition because of the differences between depositions deriving from a nuclear weapon test period and those from Chernobyl. The greatest differences, in terms of radioactivity of freshwater fishes, were the areally uneven distribution and the shortness of the time in which the Chernobyl debris deposited. Therefore, contamination of fish by radioactive substances was expected to be different from that after the nuclear weapon test period.

Concentrations of radioactive cesium in freshwater fish did not start to increase clearly until June, although the accident happened at the end of April. Traces of ^{134}Cs were already detected in May, indicating the origin of a part of the radiocesium. The delay is due to the fact that it takes for deposited radionuclides to reach fish. The length of the delay depends on the type of food which the fish eats. ^{137}Cs concentrations increased most rapidly after the accident in fishes that eat plankton, which was directly contaminated by radionuclides deposited during the period of thaw and of intense growth of new plankton in April - May. The delay was longest in predatory fishes, which get their food through a longer food chain. Therefore, the intermediate group between predators and benthic feeders had the highest concentrations of radiocesium and the group of predators the lowest. The most important representatives of these two groups were perch and pike. The differences in concentrations of radiocesium between different fish species and between the three fish groups with different feeding habits also mean that fishes get the radioactive substances from food via metabolism, not directly from water. Decrease in radiocesium content of fish was not yet noticed in 1986. Thus the uptake rate of ^{137}Cs was still greater than the rate of excretion of ^{137}Cs.

The dependence of radiocesium concentrations in fishes on the size of lakes in a deposition area is due to the fact that the greater the water volume of the lake, the more the deposited radioactive substances are diluted. Surface area is not the only factor affecting the concentrations of radioactive cesium in fish. In fact, in the case of Chernobyl fallout, the ratio of the surface area to the water volume of the lake can be regarded as an important factor determining the radioactivity level in fish in a deposition area. Besides being directly deposited on the surface of water, radioactive substances enter watersheds with runoff from the surrounding catchment area. The volume of runoff depends on many factors, for instance, the type of soil in the catchment area. It has been established that cesium is bound effectively to soil minerals, especially in clay particles, and even to suspended solids in the water [12,13]. Though sedimentation reduces the concentrations of radiocesium in the water phase, it does not necessarily reduce the amount of cesium available for aquatic food chains. Runoff also increases the amounts of radiocesium available for biota to a variable extent in different types of environment.

In the drainage basins the dependence of ^{137}Cs concentrations in fishes on areas of lakes is not so clear as in areas of different ^{137}Cs deposition (Figs. 7 - 8). The reason is that the Chernobyl deposition was areally unevenly distributed. Therefore, there are lakes of the same size with different amounts of Chernobyl fallout in one and the same drainage basin.

The dependence of the ^{137}Cs concentrations on the size of perches is partly due to the type of food that perches of different size and age eat. In their first year, perches eat mainly plankton; after that they eat insects. The food of perches 10 cm long consists of insects, worms and *Asellus aquaticus*. Later they start eating small fishes and thus begin the life of predators. Perches grow slowly, about 3 cm per year. In Finland there are numerous small ponds, in which the average size of perches is about 10 - 12 cm [19]. The food of small perches was directly contaminated by Chernobyl deposition. Bigger perches, however, were contaminated by radiocesium after a delay caused by the foodchain, and therefore the concentrations of radiocesium were lower.

The average concentration of radioactive cesium in rainbow trout is low. Concentrations of ^{137}Cs above 200 Bq kg^{-1}, found in two samples, were due to the fact that these fishes were fed with freshwater fish from the main deposition area. Normally fishes are fed with feed made of soya, Atlantic fish meal and wheat. The ^{137}Cs content of this type of feed is low.

On the basis of the results obtained to date, ^{90}Sr concentrations in freshwater fish are at the same level as before the accident [17]; only the existence of ^{89}Sr serves as a reminder of the accident.

The average intake of ^{137}Cs via freshwater fish is of the same order of magnitude as that via beef in Finland [10]. Variation in the ^{137}Cs intake via fresh water fish is, however, large, owing to the marked variation in the concentrations in freshwater fish from different lakes and different parts of Finland.

Recommendations on using fish as food were issued by STUK, for the first time in June 1986. People living in the main deposition area (fallout categories 2 - 5 in Fig. 1) were advised not to eat fish from small lakes or ponds as their main course more than 2 - 3 times a week.

The recommendation was extended in autumn 1986 to include all the lakes in the area of highest deposition (fallout categories 4 and 5 in Fig. 1). Inhabitants of the area were advised not to eat perch, pike or vendace more than 2 - 3 times a week as their main course. In addition, people were advised not to eat fish from small lakes and ponds in areas 2 - 5 in Fig. 1 as the main course more than 2 - 3 times a week, and not to eat small perches (below 10 cm) at all.

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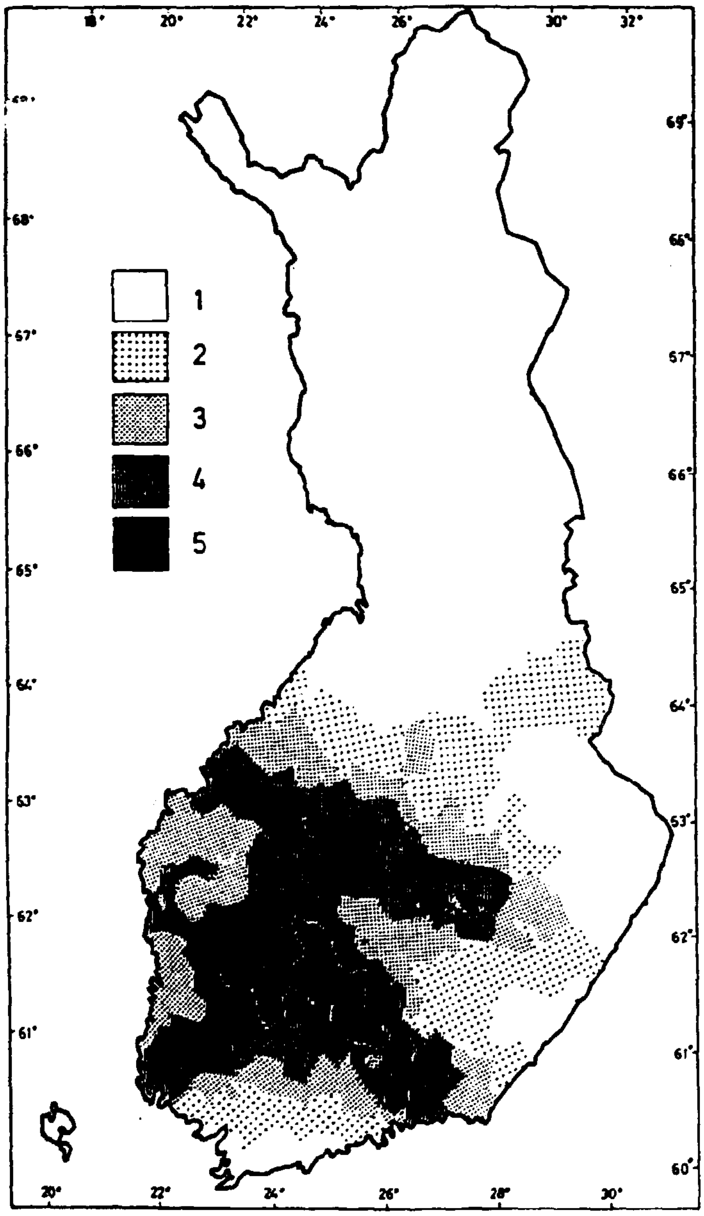

Fig. 1. Division of Finnish municipalities into five categories according to average external dose rates, caused by the Chernobyl fallout. The average ^{137}Cs deposition was calculated using an experimental calibration factor [1].

Fallout category	Deposited ^{137}Cs ($kBq\ m^{-2}$ on October 1, 1986)
1	0 - 4.3
2	4.4 - 10.1
3	10.2 - 21.7
4	21.8 - 45.0
5	45.1 - 67

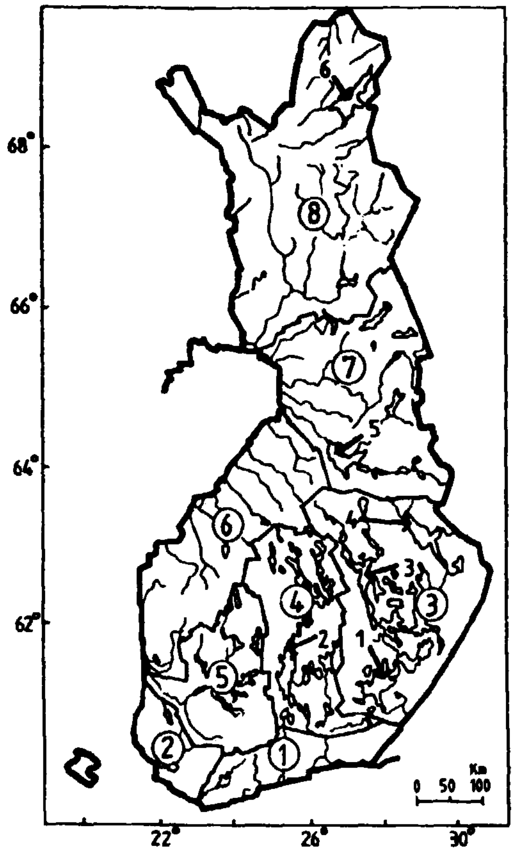

Fig. 2 The drainage basins or the statistical fishery areas (numbers 1-8 in circles) in Finland with the largest lakes:
1=Saimaa
2=Päijänne
3=Kallavesi
4=Pielinen
5=Oulujärvi
6=Inarinjärvi

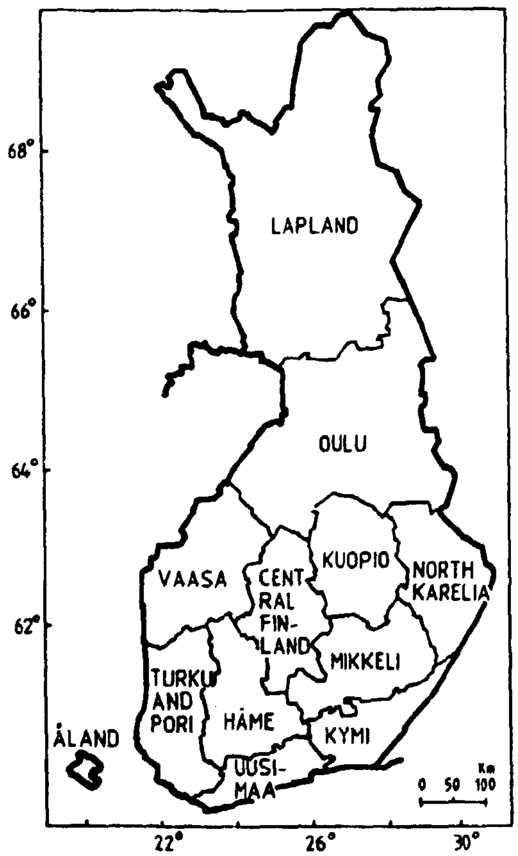

Fig. 3 The provinces in Finland.

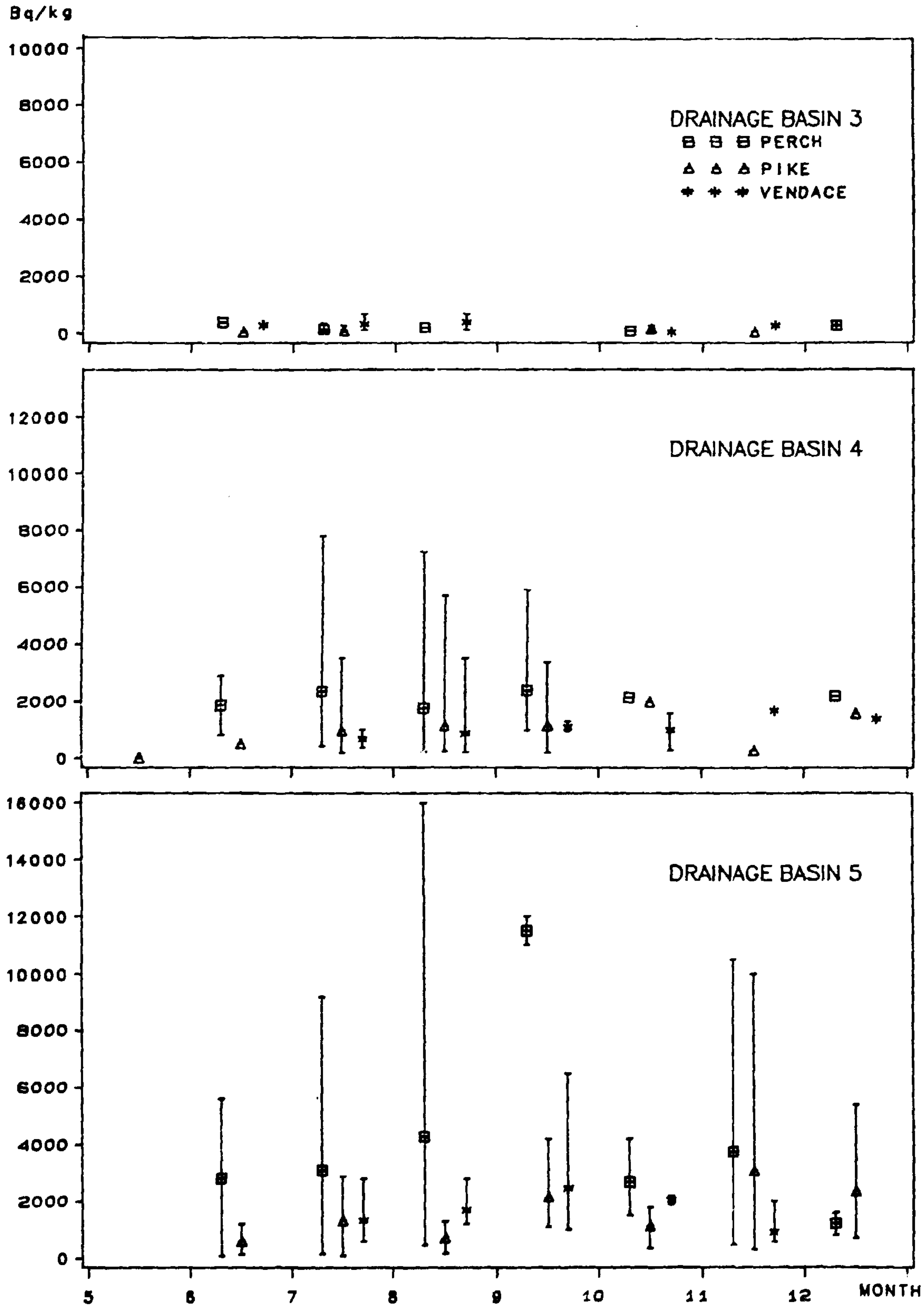

Fig. 4 **The monthly average concentrations with variation of ^{137}Cs (Bq kg^{-1} fresh weight) in perch, pike and vendace in the three most important fishery areas, 3, 4 and 5, in Finland during May-December 1986.**

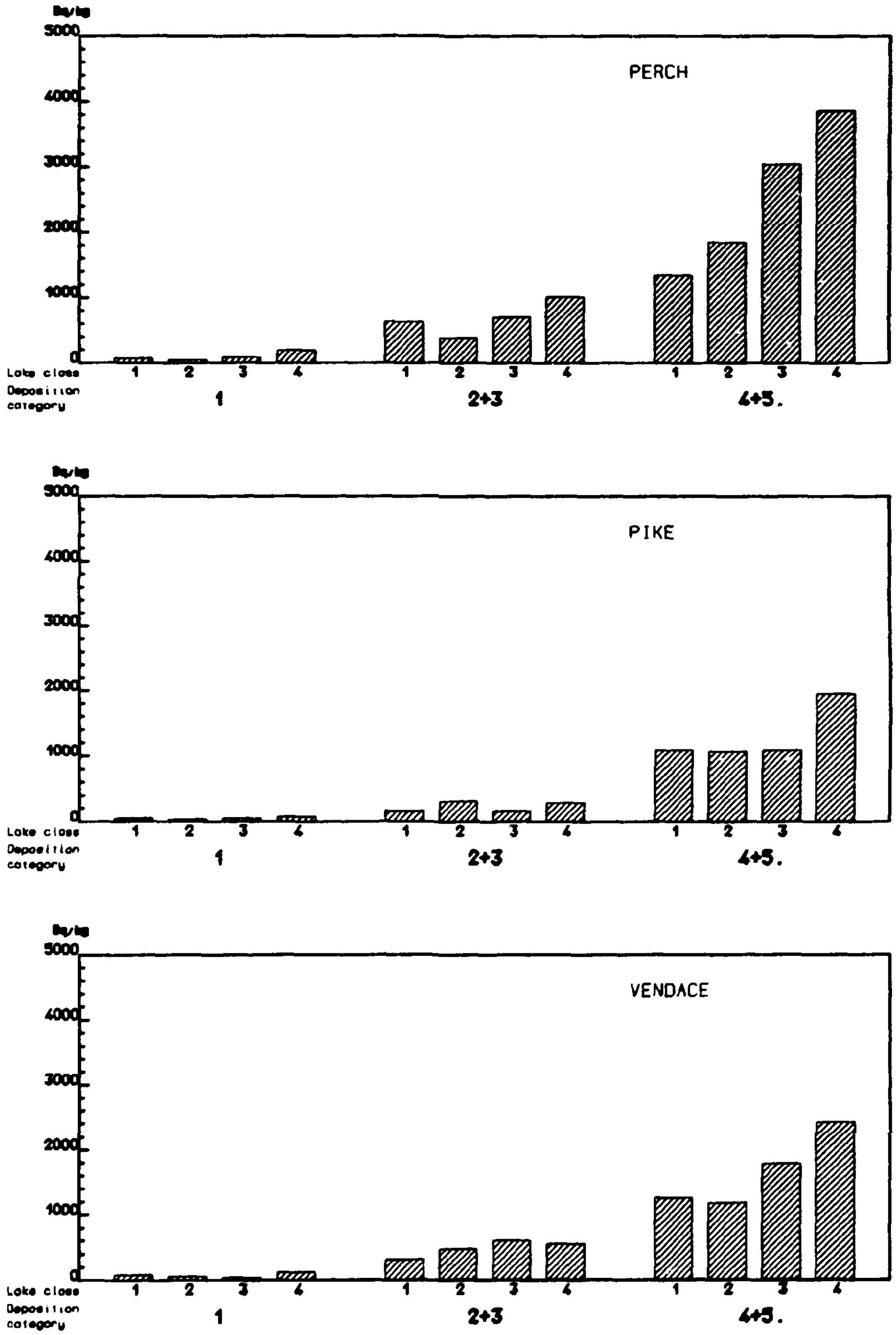

Fig. 5. The average concentrations of ^{137}Cs (Bq kg^{-1} fresh weight) in perch, pike and vendace in lakes classified according to size in areas of different deposition, after the Chernobyl accident in 1986.

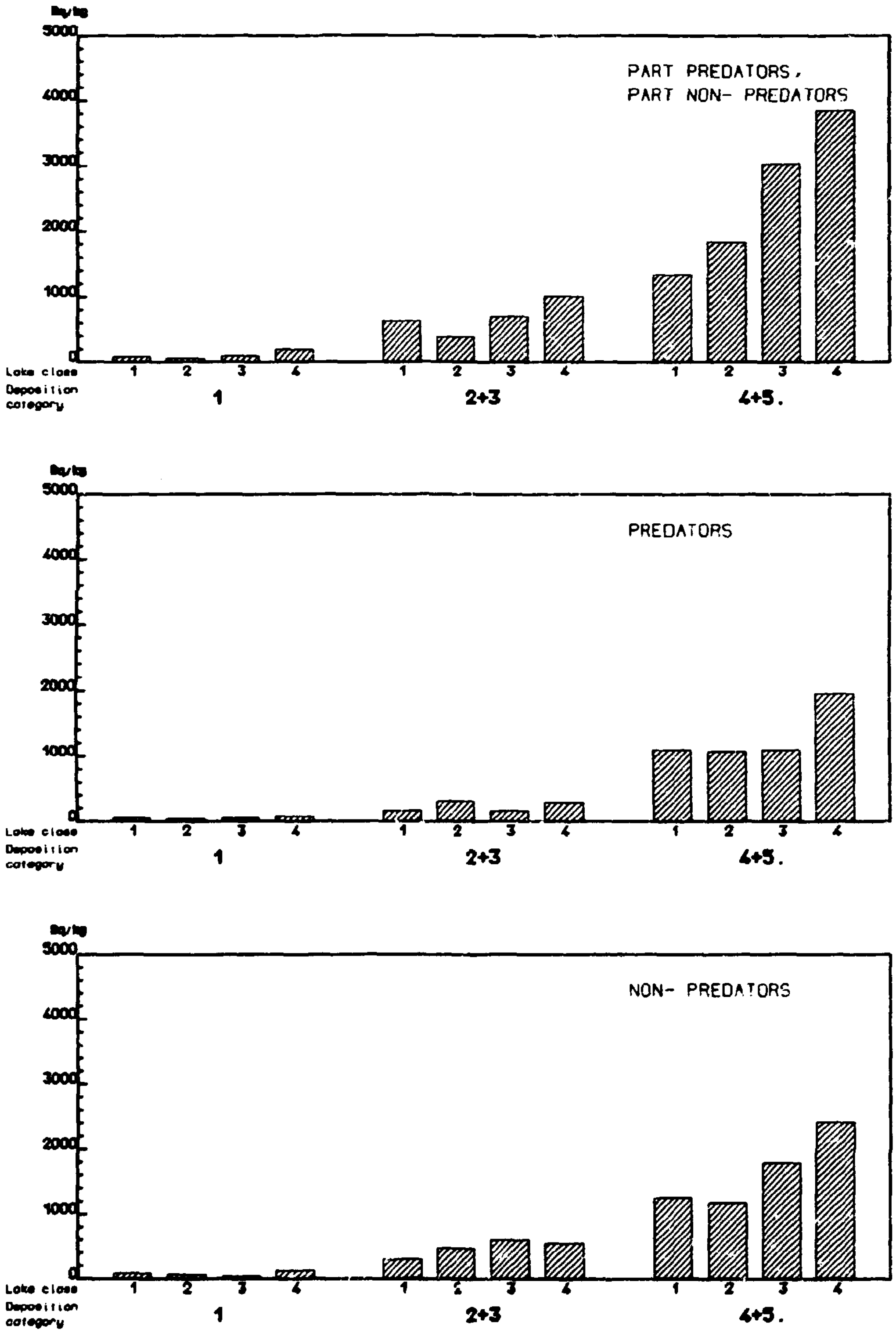

Fig. 6. The average concentrations of ^{137}Cs (Bq kg^{-1} fresh weight) in the three fish groups in lakes classified according to size in areas of different deposition, after the Chernobyl accident in 1986.

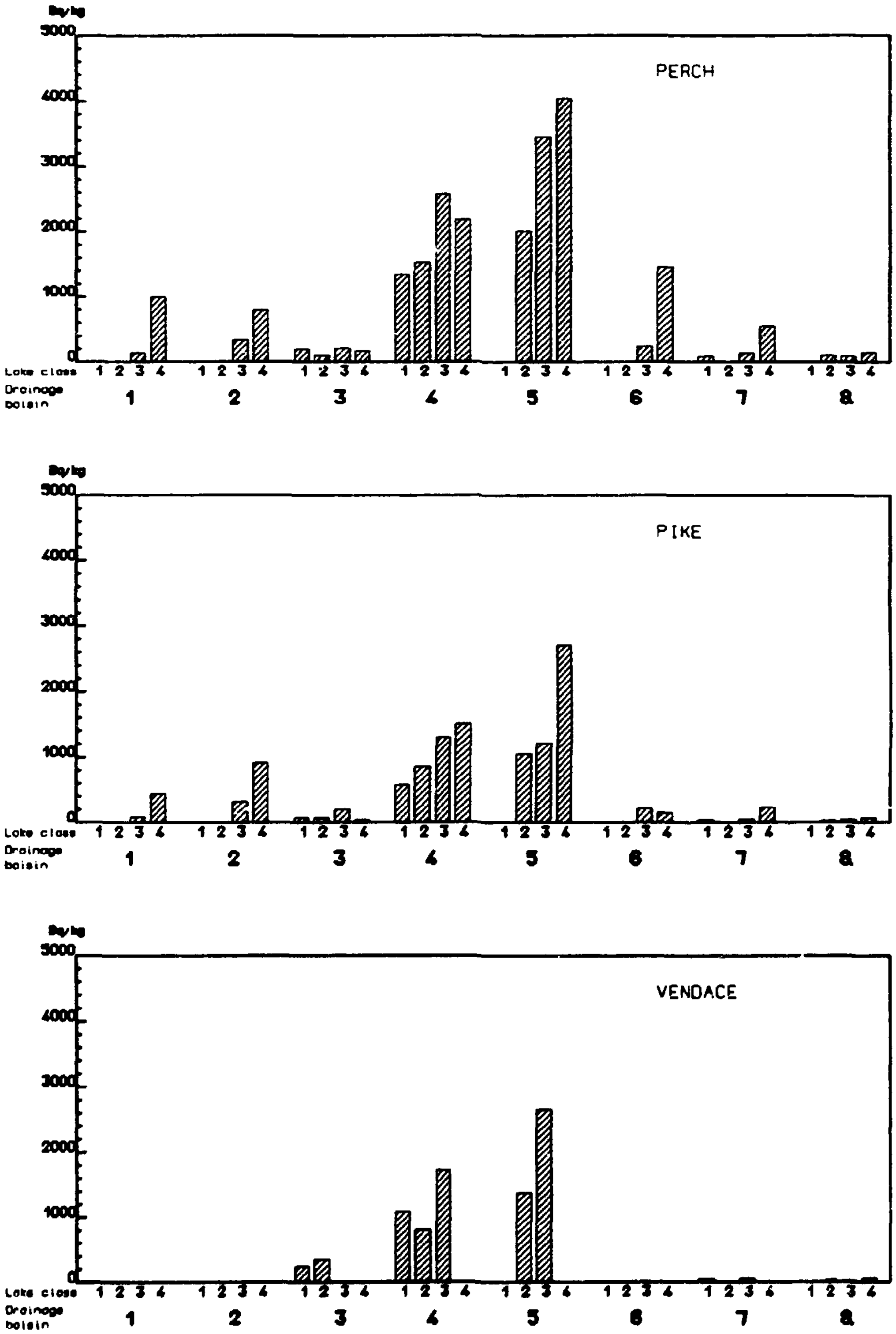

Fig. 7. The average concentrations of ^{137}Cs (Bq kg^{-1} fresh weight) in perch, pike and vendace in lakes classified according to size in drainage areas 1 - 8, after the Chernobyl accident in 1986.

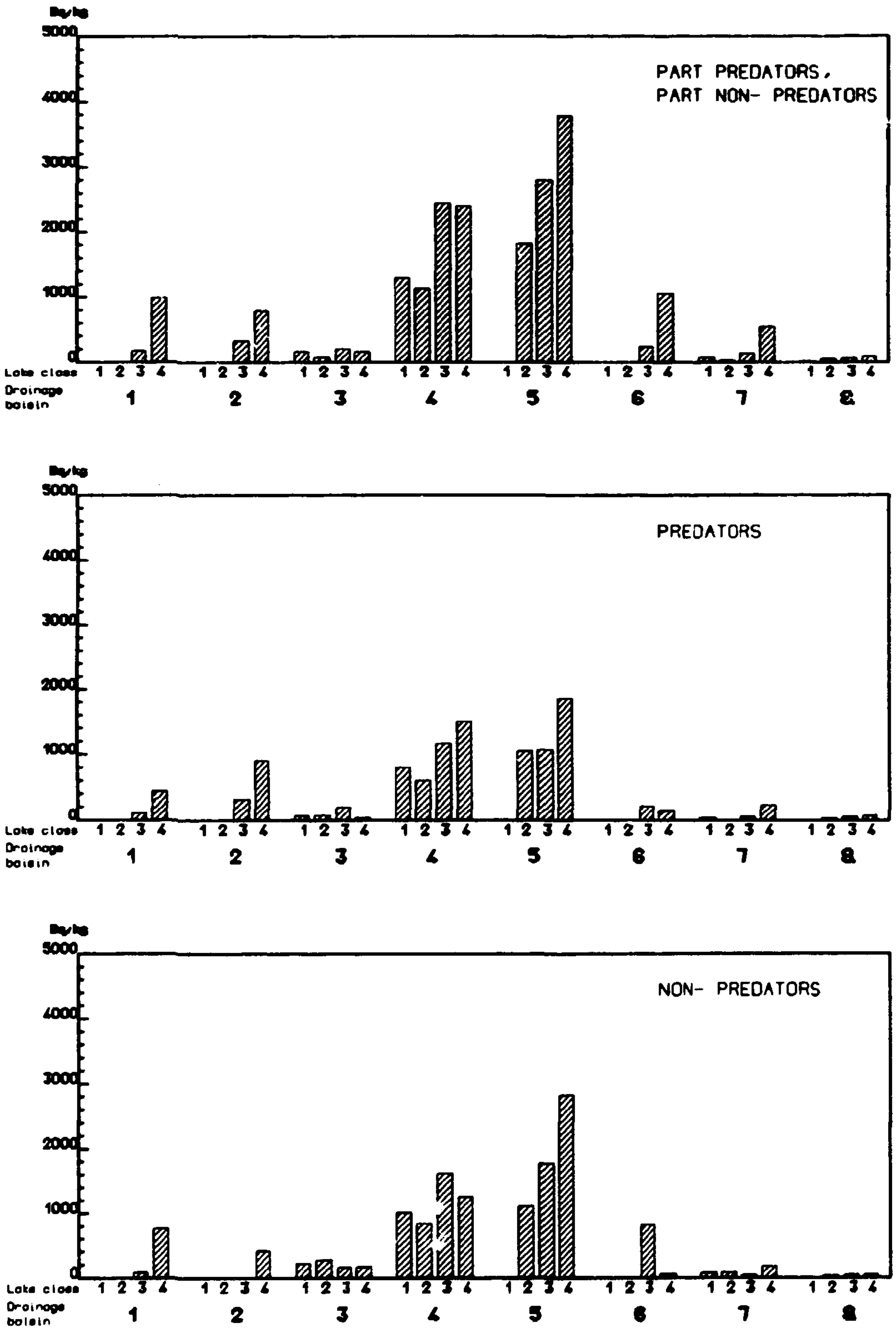

Fig. 8. The average concentrations of ^{137}Cs (Bq kg^{-1} fresh weight) in the three fish groups in lakes classified according to size in drainage areas 1 - 8, after the Chernobyl accident in 1986.

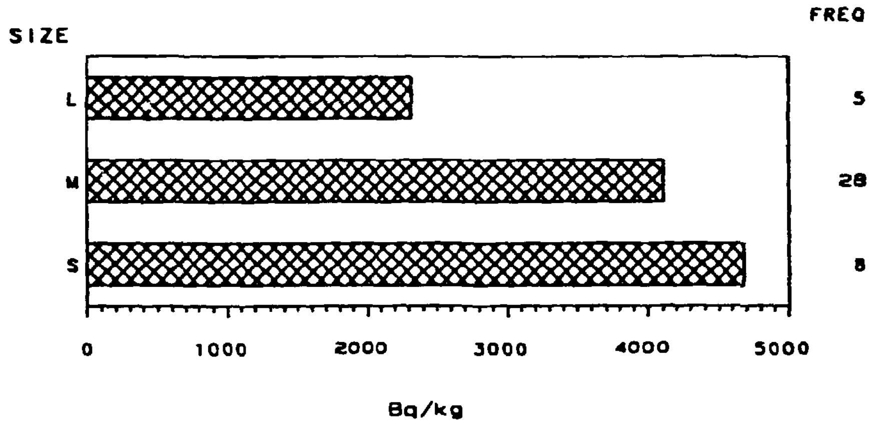

Fig. 9. The concentrations of ^{137}Cs (Bq kg^{-1} fresh weight) in perches of different size from lake class 4 (surface area < 1 km^2) in the area of highest deposition in Finland. The letters S, M and L refer to the size of individuals in the sample, S: 3 - 11 cm, M: 9 - 19 cm and L: > 20 cm. Number of samples is represented by freq.

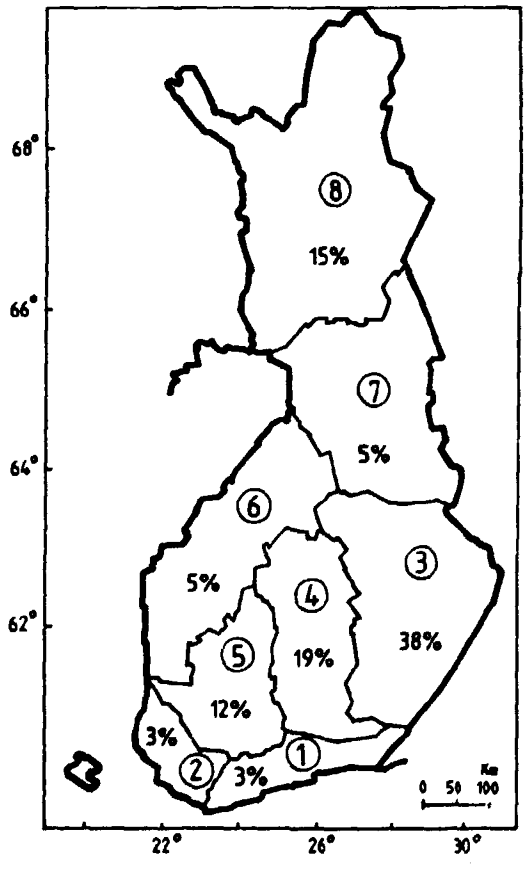

Fig. 10. The proportion of catches of freshwater fish in different drainage basins. Total catch of freshwater fish was 29 000 t in 1984-85 [8].

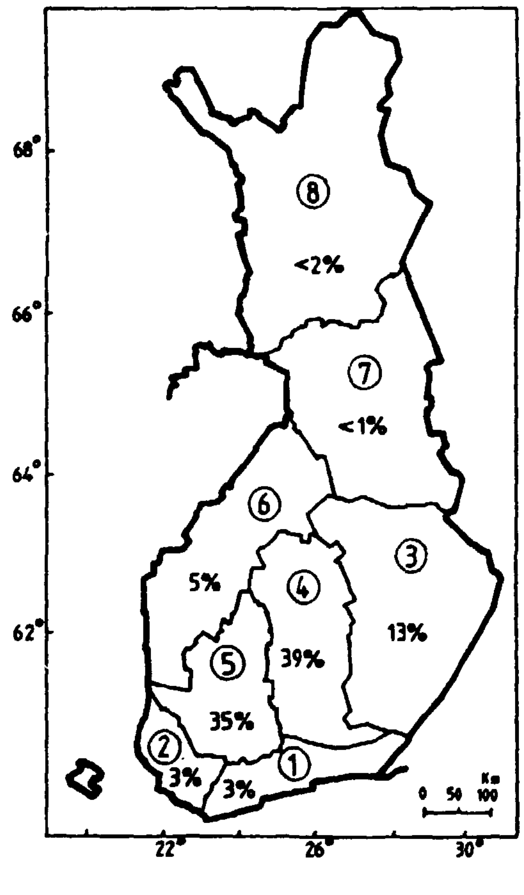

Fig. 11. The proportion of the intake of ^{137} Cs via freshwater fish in different drainage basins in 1986.

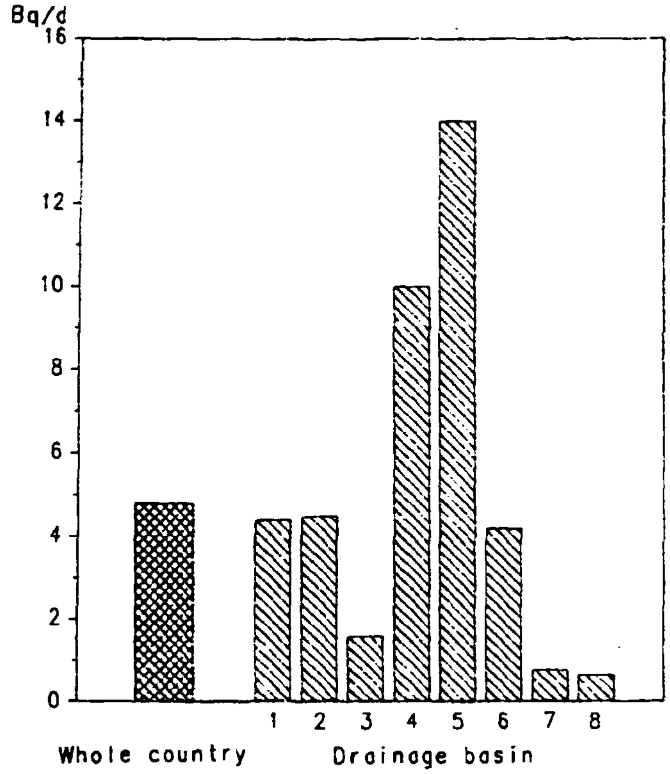

Fig. 12. The average intake of ^{137}Cs via freshwater fish in Finland and in different drainage basins, calculated using the average consumption of fresh water fish in Finland, in May-December 1986.

Table I. The average concentrations (x) and variation of ^{137}Cs (Bq kg^{-1} fresh weight) in different fish species in the largest lakes (surface area > 890 km^2, class 1) in Finland, after the accident at Chernobyl in 1986. Number of samples is also given (n).

Province Lake	Fish species		x	min, max	n
Kymi					
Saimaa	Perch	*Perca fluviatilis*	170	120, 210	2
	Vendace	*Coregonus albula*	120	110, 120	2
	Bream	*Abramis brama*	100		1
	White fish	*Coregonus lavaretus*	48		1
Häme					
Päijänne	Pike	*Esox lucius*	530		1
	Vendace	*Coregonus albula*	1600		1
	White fish	*Coregonus lavaretus*	1100		1
Central Finland					
Päijänne	Perch	*Perca fluviatilis*	1300	530,2200	5
	Pike	*Esox lucius*	580	13,1600	7
	Vendace	*Coregonus albula*	960	540,1400	4
	Roach	*Rutilus rutilus*	1250	1200,1300	2
	White fish	*Coregonus lavaretus*	830	690, 960	4
	Bream	*Abramis brama*	860	240,1800	6
	Pike-perch	*Lucioperca lucioperca*	1750	1000,2500	2
	Smelt	*Osmerus eperlanus*	1900	1500,2400	3
North Karelia					
Pielinen	Perch	*Perca fluviatilis*	88	45, 130	2
	Pike	*Esox lucius*	72		1
	Vendace	*Coregonus albula*	51		1
Kuopio					
Kallavesi	Perch	*Perca fluviatilis*	450		1
	Vendace	*Coregonus albula*	400	220, 680	3
Oulu					
Oulujärvi	Perch	*Perca fluviatilis*	86	33, 120	4
	Pike	*Esox lucius*	43	41, 45	2
	Vendace	*Coregonus albula*	52	42, 62	2
	Roach	*Rutilus rutilus*	140		1
	White fish	*Coregonus lavaretus*	42	33, 52	2
	Smelt	*Osmerus eperlanus*	67		1
Lapland					
Inarinjärvi	White fish	*Coregonus lavaretus*	16		1
	Char	*Salvelinus alpinus*	14		1

Table II. The average concentrations (x) and variation of ^{137}Cs (Bq kg^{-1} fresh weight) in different fish species in lakes with surface areas of more than 20 km^2 (class 2), after the accident at Chernobyl in 1986. About 75 % of the lakes in this class in the present study are more than 100 km^2 by area. Number of samples is also given (n).

Province Lake	Fish species		x	min, max	n
Turku and Pori					
Kyrösjärvi	Pike	*Esox lucius*	1300	1200,1300	2
	Vendace	*Coregonus albula*	1500	1200,1700	3
Pyhäjärvi	Vendace	*Coregonus albula*	590		1
Sääksjärvi	Pike	*Esox lucius*	300		1
	Vendace	*Coregonus albula*	590		1
Häme					
Kuohijärvi	Perch	*Perca fluviatilis*	3700	3100,4200	2
	Pike	*Esox lucius*	1800		1
	Vendace	*Coregonus albula*	1800	1500,2000	4
	Roach	*Rutilus rutilus*	1200	700,1600	2
	White fish	*Coregonus lavaretus*	2300		1
	Burbot	*Lota lota*	1500		1
	Lake trout	*Salmo trutta lacustris*	1600		1
Längelmä-vesi	Perch	*Perca fluviatilis*	1500	1000,1900	2
	Pike	*Esox lucius*	1000	770,1300	2
	Vendace	*Coregonus albula*	1500	1400,1500	2
	White fish	*Coregonus lavaretus*	1800		1
	Bream	*Abramis brama*	240		1
	Pike-perch	*Lucioperca lucioperca*	830		1
Näsijärvi	Perch	*Perca fluviatilis*	3200		1
	Roach	*Rutilus rutilus*	1600		1
Pälkäne-vesi	Perch	*Perca fluviatilis*	1000	460,1600	2
	Pike	*Esox lucius*	900	690,1100	2
	Vendace	*Coregonus albula*	820		1
	Roach	*Rutilus rutilus*	330		1
	White fish	*Coregonus lavaretus*	710		1
	Bream	*Abramis brama*	220		1
	Burbot	*Lota lota*	330		1
	Rudd	*Leuciscus erytrophthalmus*	420		1

Table II. Continued

Province Lake	Fish species		x	min, max	n
Pyhäjärvi	Perch	*Perca fluviatilis*	1600	1500,1600	2
	Pike	*Esox lucius*	1000	990,1100	3
	Vendace	*Coregonus albula*	2200		1
	Roach	*Rutilus rutilus*	870		1
	White fish	*Coregonus lavaretus*	470		1
	Bream	*Abramis brama*	410		1
	Silver bream	*Abramis farenus*	320		1
Roine	Vendace	*Coregonus albula*	1100	1100,1100	2
Tarjanne-vesi	Pike	*Esox lucius*	1100		1
	Vendace	*Coregonus albula*	1300		1
Vesijärvi	Eel	*Anguilla vulgaris*	1.7		1
Mikkeli					
Kyyvesi	Pike	*Esox lucius*	74		1
Pihlaja-vesi	Vendace	*Coregonus albula*	680		1
Puruvesi	Vendace	*Coregonus albula*	300		1
Puula	Perch	*Perca fluviatilis*	290	220, 360	3
	Pike	*Esox lucius*	77		1
	Vendace	*Coregonus albula*	240	190, 310	6
	Burbot	*Lota lota*	140	86, 210	3
	Smelt	*Osmerus eperlanus*	300		1
Central Finland					
Keitele	Vendace	*Coregonus albula*	1300	1000,1700	4
Kivijärvi	Perch	*Perca fluviatilis*	3300		1
	Pike	*Esox lucius*	490		1
Kynsivesi	Vendace	*Coregonus albula*	1600		1
Leppävesi	Pike	*Esox lucius*	300		1
North Karelia					
Orivesi	Perch	*Perca fluciatilis*	100	90, 100	2
	Pike	*Esox lucius*	73		1
	Vendace	*Coregonus albula*	64		1
	White fish	*Coregonus lavaretus*	31		1
	Bream	*Abramis brama*	74		1

Table II. Continued

Province Lake	Fish species		x	min, max	n
Kuopio					
Keitele	Perch	*Perca fluviatilis*	1600	1500,1700	2
	Vendace	*Coregonus albula*	980	960, 990	2
	Roach	*Rutilus rutilus*	1300		1
	White fish	*Coregonus albula*	1200		1
Konnevesi	Perch	*Perca fluviatilis*	2100	1900,2300	4
	Pike	*Esox lucius*	1100	460,2000	3
	Vendace	*Coregonus albula*	1100		1
	Roach	*Rutilus rutilus*	1200		1
	White fish	*Coregonus lavaretus*	830		1
Nilakka	Perch	*Perca fluviatilis*	1400		1
	Pike	*Esox lucius*	1100		1
	Vendace	*Coregonus albula*	960		1
	Roach	*Rutilus rutilus*	620		1
	White fish	*Coregonus lavaretus*	510		1
	Burbot	*Lota lota*	530		1
Vaasa					
Ähtärin-järvi	Perch	*Perca fluviatilis*	1500		1
	Vendace	*Coregonus albula*	1600		1
	Roach	*Rutilus rutilus*	730		1
Oulu					
Kianta-järvi	Roach	*Rutilus rutilus*	32		1
	White fish	*Coregonus lavaretus*	26		1
Muojärvi	Perch	*Perca fluviatilis*	100	83, 120	2
Vuokki-järvi	Roach	*Rutilus rutilus*	150		1
Lapland					
Kemijärvi	Pike	*Esox lucius*	21		1
	Vendace	*Coregonus albula*	4.6		1
Kilpis-järvi	Grayling	*Thymallus vulgaris*	11		1
Lokka	Pike	*Esox lucius*	31		1
Portti-pahta	Pike	*Esox lucius*	35		1
	White fish	*Coregonus lavaretus*	18	9.9 27	2
Yli-Kitka	Vendace	*Coregonus albula*	65		1

Table III. The average concentrations (x) and variation of ^{137}Cs (Bq kg^{-1} fresh weight) in different fish species in lakes smaller than 20 km^2 but larger than 1 km^2 (class 3) by surface area, after the accident at Chernobyl in 1986. Number of samples is also given (n).

Province Lake	Fish species		x	min, max	n
Uusimaa					
Huntti-järvi	Perch	*Perca fluviatilis*	180		1
	Pike	*Esox lucius*	120		1
	Roach	*Rutilus rutilus*	150		1
	White fish	*Coregonus lavaretus*	200	170, 250	3
	Bream	*Abramis brama*	85		1
	Pike-perch	*Lucioperca lucioperca*	160		1
Juusjärvi	Perch	*Perca fluviatilis*	100		1
	Roach	*Rutilus rutilus*	79		1
Kytäjärvi	Pike	*Esox lucius*	54		1
	Bream	*Abramis brama*	32		1
	Pike-perch	*Lucioperca lucioperca*	94		1
Kymi					
Musta-Ruhmas	Vendace	*Coregonus albula*	3500		1
Turku and Pori					
Ahmasvesi	Pike	*Esox lucius*	43		1
Elijärvi	Pike	*Esox lucius*	870		1
Omenajärvi	Perch	*Perca fluviatilis*	330		1
	Pike	*Esox lucius*	48		1
Rautavesi	Bream	*Abramis brama*	83		1
	Roach	*Rutilus rutilus*	170		1
Häme					
Haapajärvi	Pike	*Esox lucius*	120		1
Kaijan-selkä	White fish	*Coregonus lavaretus*	1200		1
Keihäs-järvi	Perch	*Perca fluviatilis*	3800		1
Kuivajärvi	Roach	*Rutilus rutilus*	2700		1

Table III. Continued

Province Lake	Fish species		x	min, max	n
Pääjärvi	Perch	*Perca fluviatilis*	720	460, 950	[illegible]
	Pike	*Esox lucius*	580	390, 710	3
	Vendace	*Coregonus albula*	580	570, 580	2
	Roach	*Rutilus rutilus*	330	220, 450	5
	White fish	*Coregonus lavaretus*	850	720, 970	2
	Burbot	*Lota lota*	340		1
Renkajärvi	Vendace	*Coregonus albula*	2800	2800, 2800	2
	White fish	*Coregonus lavaretus*	2300		1
Vehkajärvi	Perch	*Perca fluviatilis*	11500	11000,12000	2
	Pike	*Esox lucius*	4200		1
	Vendace	*Coregonus albula*	6500		1
	Roach	*Rutilus rutilus*	7000		1
Mikkeli					
Lääminki	Perch	*Perca fluviatilis*	1850	1500, 2400	4
	Roach	*Rutilus rutilus*	1200	1100, 1300	2
Liekune	Vendace	*Coregonus albula*	350		1
Lylyjärvi	Perch	*Perca fluviatilis*	350		1
	Pike	*Esox lucius*	52		1
	Roach	*Rutilus rutilus*	220		1
Central Finland					
Kangas-järvi	White fish	*Coregonus lavaretus*	390		1
Naula-Meronen	Perch	*Perca fluviatilis*	990		1
Niemis-järvi	Pike	*Esox lucius*	920		1
Petäjävesi	Perch	*Perca fluviatilis*	440		1
	Pike	*Esox lucius*	340		
Peurunka	Perch	*Perca fluviatilis*	2700	2600, 2700	2
	Pike	*Esox lucius*	1600		1
	Roach	*Rutilus rutilus*	1200		1
Siikavesi	Pike	*Esox lucius*	230		1
Summas-järvi	Perch	*Perca fluviatilis*	1800	1600, 2050	2
	Pike	*Esox lucius*	510		1
	Vendace	*Coregonus albula*	1300		1
	Roach	*Rutilus rutilus*	1100		1
	Bream	*Abramis brama*	1150		1
	Burbot	*Lota lota*	250		1

Table III. Continued

Province Lake	Fish species		x	min, max	n
Uurajärvi	Perch	*Perca fluviatilis*	6600	5900, 7300	2
	Pike	*Esox lucius*	2800	2200, 3400	2
	Roach	*Rutilus rutilus*	2600	2400, 2800	2
	White fish	*Coregonus lavaretus*	2600	2400, 2800	2
Kuopio					
Kuukka	Perch	*Perca fluviatilis*	190		1
	Rudd	*Leuciscus erytrophthalmus*	110		1
Melavesi	Perch	*Perca fluviatilis*	75		1
	Roach	*Rutilus rutilus*	70		1
Sulkavanjärvi	Pike	*Esox lucius*	270		1
Valvatus	Pike	*Esox lucius*	270		1
Viianvesi	Rudd	*Leuciscus erytrophthalmus*	270		1
Vaasa					
Kalajärvi	Pike	*Esox lucius*	350		1
	Roach	*Rutilus rutilus*	830		1
Oulu					
Hietajärvi	Perch	*Perca fluviatilis*	230	160, 290	2
	Pike	*Esox lucius*	87		1
Hyrynjärvi	Perch	*Perca fluviatilis*	84		1
	Vendace	*Coregonus albula*	51		1
	Roach	*Rutilus rutilus*	24		1
	Bleak	*Alburnus lucidus*	35		1
Kivarinjärvi	Perch	*Perca fluviatilis*	11		1
	Pike	*Esox lucius*	20		1
	Roach	*Rutilus rutilus*	21		1
Komujärvi	Perch	*Perca fluviatilis*	240		1
	Pike	*Esox lucius*	76		1
Oijärvi	Perch	*Perca fluviatilis*	62		1
	Bream	*Abramis brama*	37		1
Osmankajärvi	Vendace	*Coregonus albula*	61		
Pesiojärvi	Perch	*Perca fluviatilis*	40		1
	Pike	*Esox lucius*	64		1

Table III. Continued

Province Lake	Fish species		x	min, max	n
Piispan- järvi	Perch	*Perca fluviatilis*	150		1
	Pike	*Esox lucius*	70		1
Saares- järvi	Perch	*Perca fluviatilis*	230		1
Seiten- järvi	Pike	*Esox lucius*	50		1
Tyräjärvi	Vendace	*Coregonus albula*	28		1
	Roach	*Rutilus rutilus*	44		1
Lapland					
Äkäsjärvi	Pike	*Esox lucius*	61		1
	Roach	*Rutilus rutilus*	70	35, 100	2
	White fish	*Coregonus lavaretus*	32		1
Jerisjärvi	Pike	*Esox lucius*	50		1
	White fish	*Coregonus lavaretus*	56	46, 66	2
Sulkus- järvi	Char	*Salmo salvelinus*	90		1
	Trout	*Salmo trutta*	74		1
Tsarajärvi	White fish	*Coregonus lavaretus*	26		1
	Char	*Salmo salvelinus*	34		1
Vaajärvi	Perch	*Perca fluviatilis*	140		1
Vähä- Lohijärvi	Perch	*Perca fluviatilis*	35		1
	Bream	*Abramis brama*	18	12, 23	2
Vougujärvi	Grayling	*Thymallus vulgaris*	64		1

Table IV. The average concentrations (x) and variation by province of ^{137}Cs ($Bq\ kg^{-1}$ fresh weight) in different fish species in lakes with a surface area of less than 1 km^2 (class 4), after the accident at Chernobyl in 1986. Number of samples is also given (n).

Province	Fish species		x	min, max	n
Uusimaa	Perch	*Perca fluviatilis*	310	27, 840	3
	Pike	*Esox lucius*	440		1
	Roach	*Rutilus rutilus*	230		1
Kymi	Perch	*Perca fluviatilis*	1300	270, 3100	6
	Pike	*Esox lucius*	600	430, 750	3
	Roach	*Rutilus rutilus*	1000	280, 1400	3
	White fish	*Coregonus lavaretus*	990		1
	Bream	*Abramis brama*	330		1
Turku and Pori	Perch	*Perca fluviatilis*	3900	150, 9200	14
	Pike	*Esox lucius*	1200	67, 2900	7
	Roach	*Rutilus rutilus*	1700	1600, 1700	2
	Bream	*Abramis brama*	420		1
Häme	Perch	*Perca fluviatilis*	4000	64,16000	32
	Pike	*Esox lucius*	2400	170,10000	19
	Roach	*Rutilus rutilus*	2500	490, 6100	17
	White fish	*Coregonus lavaretus*	3500	770, 6800	17
	Bream	*Abramis brama*	2500	21, 4500	5
	Burbot	*Lota lota*	1100	87, 3600	8
	Eel	*Anguilla vulgaris*	380	280, 480	2
	Crusian carp	*Cyprinus carassius*	9300		1
Mikkeli	Perch	*Perca fluviatilis*	570	120, 1800	5
	Roach	*Rutilus rutilus*	410	350, 470	2
	Bream	*Abramis brama*	200		1
Central Finland	Perch	*Perca fluviatilis*	2600	390, 7800	9
	Pike	*Esox lucius*	2100	230, 5700	5
	Roach	*Rutilus rutilus*	1400	630, 2500	5
	White fish	*Coregonus lavaretus*	5900	4700, 7100	2
	Bream	*Abramis brama*	1600		1
North-Carelia	Pike	*Esox lucius*	24		1
Kuopio	Perch	*Perca fluviatilis*	110	82, 140	4
	Pike	*Esox lucius*	47	40, 54	2
	Roach	*Rutilus rutilus*	90	40, 180	3
	White fish	*Coregonus lavaretus*	160	49, 380	3
	Silver bream	*Abramis farenus*	49	48, 50	2
	Rudd	*Lauciscus eryrophthalmus*	31		1
Vaasa	Perch	*Perca fluviatilis*	2700	1200, 4600	3
	Pike	*Esox lucius*	260		1

Table IV. Continued

Province	Fish species		x	min, max	n
Oulu	Perch	*Perca fluviatilis*	370	84, 1300	11
	Pike	*Esox lucius*	140	27, 260	5
	Roach	*Rutilus rutilus*	160	44, 480	5
	White fish	*Coregonus lavaretus*	320	59, 580	2
	Ide	*Leuciscus idus*	50		1
Lapland	Perch	*Perca fluviatilis*	150	45, 330	7
	Pike	*Esox lucius*	75	48, 150	18
	Vendace	*Coregonus albula*	59	31, 84	4
	Roach	*Rutilus rutilus*	42	39, 45	2
	White fish	*Coregonus lavaretus*	80	15, 220	7
	Burbot	*Lota lota*	25		1
	Trout	*Salmo trutta fario*	37	21, 52	6
	Grayling	*Thymallus vulgaris*	20		1
	Sea trout	*Salmo trutta*	41		1

Table V. ^{89}Sr and ^{90}Sr (Bg kg^{-1} fresh weight) in fresh water fish in 1986. Locations of the lakes Inarinjärvi, Oulujärvi and Saimaa are given in Fig. 2. Puruvesi is in drainage basin 3, Nilakka in drainage basin 4 and Längelmävesi in drainage basin 5.

Lake	Fish species	Date of sampling	^{89}Sr	^{90}Sr
Längelmävesi	Pike-perch	22.8.86	0.4	0.49
Oulujärvi	Perch	1.8.86	9	17
	Pike	1.8.86	8	0.63
Puruvesi	Vendace	29.6.86	10	8.1
Saimaa	Vendace	31.7.86	2	5.0
Inarinjärvi	White fish	5.7.86	20	0.86
Nilakka	Rainbow trout	15.7.86	0.1	0.30

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Finnish Centre for Radiation and Nuclear Safety
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