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RADIOACTIVITY OF FUCUS VESICULOSUS ALONG THE FINNISH COAST IN 1987

Supplement 9 to Annual Report 1987 (STUK-A74)

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ABSTRACT

Samples of *Fucus vesiculosus* were collected along the west and south coast of Finland at 25 stations in June-October 1987. More detailed surveys were conducted in the marine areas surrounding the nuclear power stations at Olkiluoto and Loviisa. The samples were analysed for gamma-emitting radionuclides and partly also for ^{90}Sr and transuranic elements.

From the twelve gamma-emitting radionuclides detected in the *Fucus* samples, ^{40}K, ^{106}Ru, ^{110m}Ag, ^{134}Cs and ^{137}Cs were found in nearly all samples. ^{54}Mn and ^{65}Zn were almost regularly detected in the samples from the Olkiluoto and Loviisa areas and commonly also along the whole coast, whereas ^{60}Co was rarely found at the coastal stations outside the immediate vicinities of the power stations.

The activity concentrations of ^{137}Cs varied in the *Fucus* samples from 80 to 670 Bq kg^{-1} dry weight. The highest values were found in the Loviisa area and in the eastern part of the Gulf of Finland and the lowest in the Archipelago Sea. The values reflect differences in the amounts of local fallout and runoff, but also the transport of radionuclides by river waters and currents in the sea.

The results provide evidence of the indicator value of *Fucus vesiculosus* in the monitoring of radioactive substances, both in the environs of the nuclear power stations and also in studies regarding the dispersion and behaviour of fallout nuclides in the marine environment. Among the great number of samples taken in the Finnish monitoring programme, *Fucus* was the most sensitive bioindicator of ^{60}Co and ^{65}Zn, and thus enabled detection of these radionuclides in the fallout from Chernobyl.

CONTENTS

1 INTRODUCTION

The bladder-wrack, *Fucus vesiculosus*, is a tall brown alga growing in the littoral zones of the Baltic Sea and most of the northern North Atlantic region. *Fucus* communities form a significant part of the ecosystem, especially in the northern Baltic Sea area, where the littoral vegetation in general is poor in species owing to the low salinity of water. *Fucus* belts provide shelter and a source of nourishment for fish of different stadia and for other aquatic organisms, but the value of *Fucus* for human use is slight, at least in Finland.

Because of its extensive distribution, common occurrence and significance in the ecosystem, the bladder-wrack has generally been considered to be an excellent medium of environmental monitoring. Owing to its ability to accumulate radionuclides (and other substances), it has widely been used as a bioindicator of radioactivity in the marine environment. By means of bioindicators, it is easier to detect low levels of harmful substances in the environment than directly from water (analogously from air or soil).

In the Baltic Sea area *Fucus vesiculosus* has been used as a bioindicator of radioactivity by most of the countries bordering the sea. [2,18] In Finland it was chosen to be sampled for environmental monitoring in the marine areas surrounding the nuclear power stations already in the 1960s, when biological background studies were started. A preceding *Fucus* survey along the Finnish coast was carried out in 1980 - 1981. [7,8]

In 1987, one year after the Chernobyl accident, the survey was repeated by the Finnish Centre for Radiation and Nuclear Safety (STUK), in order to monitor the areal distribution of the fresh fallout in the coastal waters of Finland. Special attention was paid to the monitoring of reactor-induced radionuclides in the environs of the Olkiluoto and Loviisa nuclear power stations.

The survey included the whole Finnish coast, except that of the Bothnian Bay, where *Fucus vesiculosus* does not occure due to the low water salinity. *Fucus* samples were analysed for gamma-emitting radionuclides and partly also for ^{90}Sr and transuranic elements. In addition, a selected number of sea water samples was analysed gammaspectrometrically.

2 MATERIALS AND METHODS

2.1 Sampling

Samples of *Fucus* were collected along the west and south coast of Finland at 25 stations in June - October 1987. Locations of the coastal stations are shown in Fig.1. More detailed surveys were conducted in the marine areas surrounding the nuclear power stations at Olkiluoto and Loviisa. Samples were taken at 13 stations in both areas (Figs. 2 and 3). The exact sampling positions are given in Table I. Besides the sampling of *Fucus*, water salinities were measured at each station (Table I), and larger water samples (40 l) were also taken at 12 stations for analysing of gamma-emitting radionuclides. Observations were also made on the abundance and state of *Fucus* at all sampling localities (Table II).

The research boat of the STUK was used for most of the sampling. However, in order to reduce costs the stations B,C,D,H,I,J and L were visited by car. This caused difficulties especially at the northernmost stations because the coastal waters there are mostly shallow and *Fucus* occurs less frequently due to the decreasing salinity of water. Thus it is hard to reach good sampling locations by land, and in most cases one must be satisfied with poorly growing algae specimens. The sampling station A at Norrskär was visited with the assistance of the Coast Guard of the Gulf of Bothnia (Vallgrund). Norrskär lies at the northernmost point of the constant distribution range of *Fucus vesiculosus* in Finland. [8] The algae there are clean and healthy, but rare and small in size (Table II). We also tried to get samples from the region between stations A and B, but without success, in spite of checking of several shore areas. The sample from station K was obtained with the assistance of a club of divers.

All the samples were taken using the SCUBA diving technique. The diver collected the algae one by one in a net bag. Only well-developed and attached (haptophytic) individuals were

chosen, and the entire thalli including the basal parts were sampled. Each sample comprised numerous individuals, because *Fucus* is relatively small in size on the Finnish coast and the amount needed for analyses was 1.5 kg fresh wt. The samples for quantitative biomass studies were taken with a diver-operated *Fucus* bag (0.20 m^2) described by the Finnish IBM-PM group. [4] The water samples were taken directly from the surface of the water to plastic kegs (volume 20 l).

2.2 Pre-treatment

Fucus

Fucus samples for radionuclide analyses were shaken thoroughly on porous paper immediately after sampling. Then they were preliminarily dried at room temperature in the field laboratory or in the boat. The final drying was performed at 105 °C overnight, and the dry weight was recorded. The samples for gammaspectrometric measurements were ground. Plutonium analyses were performed from dried and strontium analyses from ashed (450 °C) material.

The fresh weight/dry weight ratio was determined from the biomass samples taken with the *Fucus* bag. Samples were shaken thoroughly immediately after sampling and put into tightly sealed plastic bags. The bags were frozen in the field laboratory for storage. The frozen weight was recorded as the fresh weight. The dry weight was determined after drying overnight at 105 °C.

Water

Water samples of 35-45 l were evaporated to near dryness and the salt-jelly was measured gammaspectrometrically.

Three water samples were filtered through 0.45 μm Millipore membrane filters and the filtrates and filters were measured gammaspectrometrically separately. The filtrates were evaporated, and the air dry filters were pressed into discs.

2.3 Gammaspectrometric analyses

The gammaspectrometric measurements were performed with three semiconductor detectors, one of which is an n-type HPGe-crystal, the others being lithium drifted. The relative efficiencies are 15-20% and energy resolution about 2.0 keV at 1332.5 keV. The detectors are background shielded with 12-cm-thick lead lined with copper (2 mm).

Most of the samples were measured in Marinelli-geometry. When there was not enough material for the Marinelli-beaker, some samples were measured in cylindrical plastic containers with diameters of 95 mm.

The measured spectra were analysed by computer programme, which takes into account coincidence summing and self-absorption corrections. [16,17] The measurement error for ^{40}K and the cesium isotopes was about 5-10 % and for other nuclides 10-30 %, depending on activity.

2.4 Strontium analyses

Strontium analyses were performed using the nitric acid precipitation method. ^{90}Sr was determined after ingrowth of its daughter nuclide ^{90}Y to the equilibrium activity.[3] The purified daughter nuclide was measured with a low-background beta counter with continuous argon methane gas flow. The total error of ^{90}Sr analyses was 10 %.

2.5 Analyses of transuranic elements

Dried *Fucus* samples were wet ashed and acid leached for plutonium analysis. Plutonium was separated from the oxidized sample solution by anion exchange and reduction. The radioactivity of the electrodeposited sample was measured alfaspectrometrically. ^{242}Pu was used as a tracer. The chemical yields varied from 60 % to 100 %, the total errors being about 10 % for $^{239,240}Pu$ and 20 % for ^{238}Pu. [19]

3 RESULTS

Twelve gamma-emitting radionuclides were detected in the *Fucus* samples (Tables III,IV and V) and five in the water samples (Table VI). Only a limited number of samples were analysed for ^{90}Sr, ^{238}Pu and $^{239,240}Pu$. From the twelve gamma nuclides ^{40}K, ^{106}Ru, ^{110m}Ag, ^{134}Cs and ^{137}Cs were found in nearly all algae samples. ^{54}Mn and ^{65}Zn were almost regularly detected in the samples of the Olkiluoto and Loviisa areas and commonly also along the whole coast, whereas ^{60}Co was less frequent at the coastal stations outside the immediate vicinities of the power stations. ^{51}Cr and ^{58}Co occurred only in a couple of samples taken from the Olkiluoto area.

The activity concentrations of ^{137}Cs varied in the *Fucus* samples from 80 to 670 Bq kg^{-1} dry weight. The highest values were found in the Loviisa area and in the eastern part of the Gulf of Finland and the lowest in the Archipelago Sea (Fig. 4, Tables III-V). Besides the values for the coastal stations, Fig. 4 also includes those for the outermost stations of the Olkiluoto and Loviisa areas. The lowest concentration of ^{137}Cs in sea water was also found in the Archipelago Sea (100 Bq m^{-3}), but the highest values were in the Bothnian Sea (260-430 Bq m^{-3}). In the Loviisa area about 1 % of ^{137}Cs was in particulate form in water, while at station A (Norrskär) the share was about 3 % (Table VI).

The ratio $^{134}Cs/^{137}Cs$ in the algae samples was 0.40 $\pm$ 0.01 in the Loviisa area and in the eastern part of the Gulf of Finland and 0.37 $\pm$ 0.01 at the other sampling stations. The difference was due to the fact that the samples were taken from the eastern Gulf of Finland 1-2 months earlier than elsewhere. In sea water the ratio was, on average, 0.38 $\pm$ 0.02.

The highest ^{106}Ru concentrations (maximum 90 Bq kg^{-1} dry weight) in *Fucus* were in the innermost stations of the Loviisa area,

whereas the ^{54}Mn and ^{60}Co values were highest (maxima 85 and 62 Bq kg^{-1} dry weight) at Olkiluoto. ^{54}Mn and ^{60}Co were also detected in low concentrations (below 4 Bq kg^{-1} dry weight) at several stations outside the environs of the nuclear power stations (Table III). ^{65}Zn and ^{110m}Ag occurred quite evenly along the whole coast (except the Archipelago Sea and the western and central parts of the Gulf of Finland), the concentrations in *Fucus* being < 10 and < 30 Bq kg^{-1} dry weight, respectively.

The activity concentrations of ^{90}Sr varied in the algae samples from 13 to 27 Bq kg^{-1} dry weight. The $^{239,240}Pu$ concentrations varied considerably, being in general about 0.12 - 0.17 Bq kg^{-1} dry weight. The corresponding ^{238}Pu values ranged from 0 to 0.16 Bq kg^{-1} dry weight.

4 DISCUSSION

The study was carried out more than one year after the Chernobyl accident. The activity concentrations of ^{137}Cs in *Fucus vesiculosus* were at their highest in May 1986, when the maximum values were 4900 and 1300 Bq kg^{-1} dry weight in the Loviisa and Olkiluoto areas.[10,11] In 1987 the concentrations of radionuclides were much lower and more even both in algae and sea water (cf. Ref. 6). At Loviisa and Olkiluoto the ^{137}Cs values in *Fucus* were only 16-17 % of those given above (Fig. 5). However, there were still marked areal differences in radionuclide concentration, partly due to the scattered nature of the fallout from Chernobyl, and partly due to discharges from the local nuclear power stations.

The ^{137}Cs concentrations in *Fucus* were 480-670 Bq kg^{-1} in the inner part of the Loviisa area, 360-470 Bq kg^{-1} in the outer part of the area and in the eastern part of the Gulf of Finland, 130-200 Bq kg^{-1} in the central and western Gulf of Finland, 80-100 Bq kg^{-1} in the Archipelago Sea, 170-300 Bq kg^{-1} in the waters surrounding Aland and 130-230 Bq kg^{-1} in the Bothnian Sea, with the exception of the Kristiinankaupunki-Merikarvia region (stations C and D), where the concentrations were 320-340 Bq kg^{-1} (Fig. 4). The values reflect differences in the amounts of local fallout and runoff, but also the transport of radionuclides by river waters and currents in the sea. For example, the higher values in the Kristiinankaupunki-Merikarvia region can be explained by the influence of the River Kokemäenjoki, the drainage basin of which belongs to the main fallout area in Finland.[14] The main currents of the Bothnian Sea flow anticlockwise so that the radioactivity discharged by the River Kokemäenjoki is tranported north along the Finnish coast. Correspondingly, on the Swedish coast the currents mostly flow southwards. Thus the higher values of ^{137}Cs on the north and west coasts of Aland may have been caused by waters transported from the

Gävle district, which forms the main fallout area in Sweden.[5]

The influence of river waters was also clear in the eastern part of the Gulf of Finland, where e.g. the Rivers Neva and Kymijoki and many other rivers from Finland and USSR inflow. The drainage area of the River Kymijoki received a marked proportion of the Chernobyl fallout in Finland.[14] The effect of river waters was also apparent in the sediment samples taken from the eastern Gulf of Finland in 1987.[6]

The concentration factors (CF) from water to *Fucus* were distinctly higher in the eastern Gulf of Finland than in the Archipelago Sea and the Gulf of Bothnia. In this study the CF values were about 2000 at the stations Loviisa 3 and 5 and at the station Y of Ulko-Tammio. At the other stations, where water samples were taken, the CF values varied between 400 and 800. In our earlier study in 1982-1983 [12], the CF values were less variable, being 610-1100 in the eastern part of the Gulf of Finland and 400-920 in other parts of the coast. There is a negative correlation between the concentration factor of ^{137}Cs in *Fucus* and the water salinity (Fig. 6). However, the salinity of water is probably not the only factor affecting the accumulation rate, but also e.g. the humic substances in water, etc.[9,12] The impact of river waters was exceptionally high during the early and mid-summer 1987 in the eastern Gulf of Finland. Thus the three lowest salinity values presented in Fig. 6. are not characteristic of those stations.

The highest activity concentrations of ^{134}Cs and ^{137}Cs were found in Hästholmsfjärden at Loviisa (stations 1-3), as was the case already in May 1986 (see p. 14). The possible reasons for the high values in Hästholmsfjärden are the larger amount of fallout in the area, the location close to the mouth of the River Kymijoki, the limited water exchange in the semi-enclosed Hästholmsfjärden bay and the local discharges. Before the Chernobyl accident, the ^{137}Cs concentrations in *Fucus* were 10-15 Bq kg^{-1} both in the environs of the Loviisa nuclear power station and elsewhere along the south coast of Finland. Because the

amounts of ^{134}Cs and ^{137}Cs have been quite even in the discharges of the Loviisa power station during recent years, there is reason to believe that the increase in cesium values in Hästholmsfjärden is caused by the Chernobyl fallout.

The highest concentrations of ^{134}Cs and ^{137}Cs just in the vicinity of the cooling water outlet may partly be caused by the impact of elevated temperature on the accumulation rate (cf. also stations 8 and 9 at Olkiluoto). There are also indications, that in general the radionuclide concentrations are higher in the poorly growing and brittle *Fucus* thalli, which were characteristic of the areas near the outlets of the power plants and also e.g. of the stations C and D at Kristiinankaupunki and Merikarvia (see Table II). In addition to ^{137} Cs and ^{134} Cs, ^{106} Ru was also most abundantly detected in Hästholmsfjärden at Loviisa.

The activity concentrations of ^{60}Co in *Fucus* in the Loviisa area were at about the same level as in 1980.[7] The distribution pattern was also similar. The concentrations in the semi-enclosed bay of Hästholmsfjärden (stations 1-3) were less dependent on the distance from the outlet, whereas in the outer sea area the concentrations decreased rapidly (Fig. 7).

At Olkiluoto, the reduction of ^{60}Co in *Fucus* with respect to the distance from the outlet, can be represented by the following power function[20]

$$C = a \cdot D^{-b}$$

where
- C is concentration in *Fucus*
- D is distance from the outlet
- a is a factor depending, e.g. on the amount of discharged ^{60} Co and its accumulation rate to *Fucus*
- b is a factor depending, e.g. on the topography of the discharge area and water currents there and the sedimentation rate of the nuclide

According to this study, the average value of *b* is 1.3. In our earlier study the corresponding value was 0.8.

The origin of ^{60}Co seems to be mostly local, although there are also some indications of ^{60}Co in the Chernobyl fallout. Small amounts of ^{60}Co have been detected in peat ash and after chemical separation in an air sample collected on April 28, 1986 at the STUK.[1] ^{60}Co has also been reported in algae samples taken from the Swedish coast of the Bothnian Sea in 1986.[5] The small amounts of ^{60}Co in our coastal stations D, E, F, J and K may originate either from the drainage area of the River Kokemäenjoki and the Gävle district, or from the nuclear power stations at Olkiluoto and Forsmark. However, trace amounts of ^{60}Co were more widely distributed along the whole coast. (When samples contain greater amounts of ^{110m}Ag and ^{134}Cs the limit of certain observations of ^{60}Co is elevated. Only certain observations are presented in Tables III-V.)

There has been no clear evidence of ^{65}Zn in the fallout from Chernobyl. Zinc was not detected in the deposition samples collected in Finland after the accident,[15] but traces of it were found in some cereal and meat samples.[13] It was also found in *Fucus* samples collected from the Loviisa area in August 1986, although no ^{65}Zn discharges have been reported from the Loviisa nuclear power station. In this study ^{65}Zn was detected in *Fucus* along the whole coast, except in the Archipelago Sea and the western part of the Gulf of Finland, where the concentrations of all fallout nuclides were lowest. In the Olkiluoto area most of ^{65}Zn originates from the discharges of the power station, but its distribution pattern differs to some extent from that of ^{60}Co (Fig. 8). The occurrence of ^{65}Zn in *Fucus* samples, even if it has not been detected in the atmospheric deposition, is explained by its high affinity to *Fucus*.

In general, ^{54}Mn was found in the same samples as ^{65}Zn. It is one of the nuclides regularly reported in the discharges of the Finnish nuclear power stations, but small amounts of ^{54}Mn were also detected in deposition.[6,14] The distribution pattern of ^{54}Mn was similar to that of ^{60}Co in both nuclear power station

areas (Figs 7 and 8).

The results provide evidence of the indicator value of *Fucus vesiculosus* in the monitoring of radioactive substances, both in the environs of nuclear power stations and also in studies regarding the dispersion and behaviour of fallout nuclides in the marine environment. Among the great number of samples taken in the Finnish monitoring programme, *Fucus* was the most sensitive bioindicator of ^{60}Co and ^{65}Zn, and thus enabled detection of these radionuclides in the fallout from Chernobyl.

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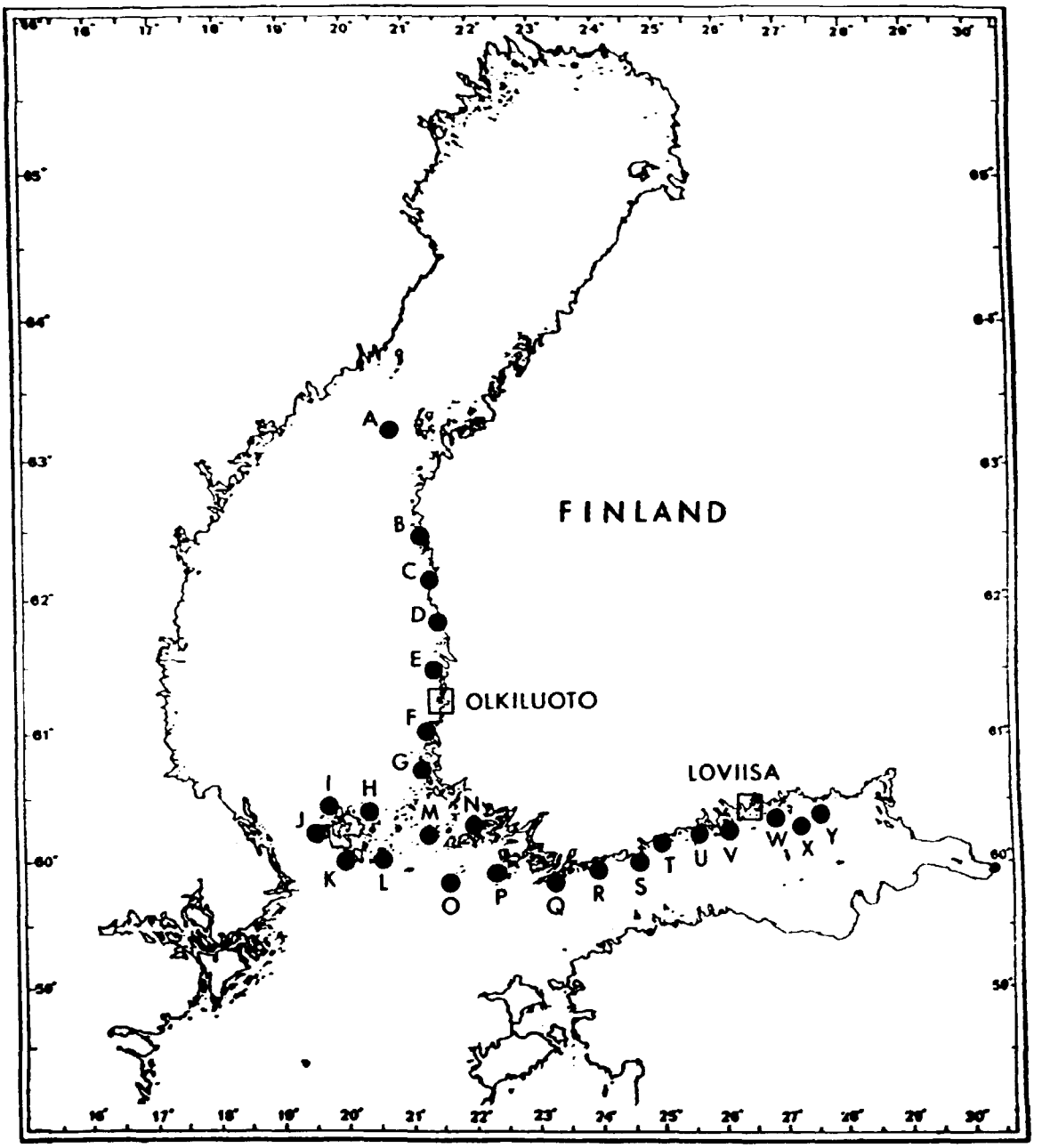

Fig. 1. Sampling stations along the Finnish coast.

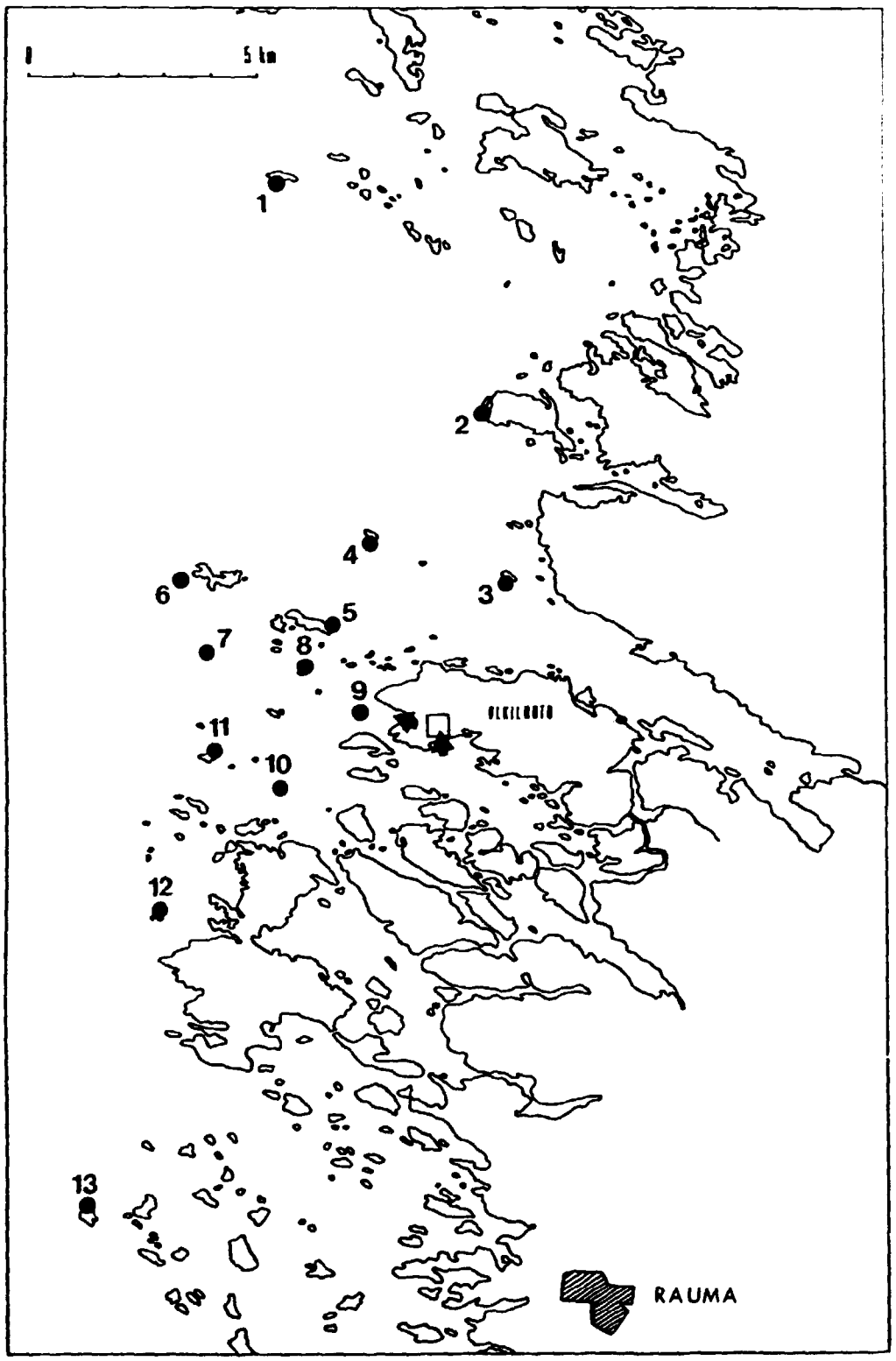

Fig. 2. Sampling stations in the sea area around Olkiluoto. The cooling water intake and outlet are marked with arrows.

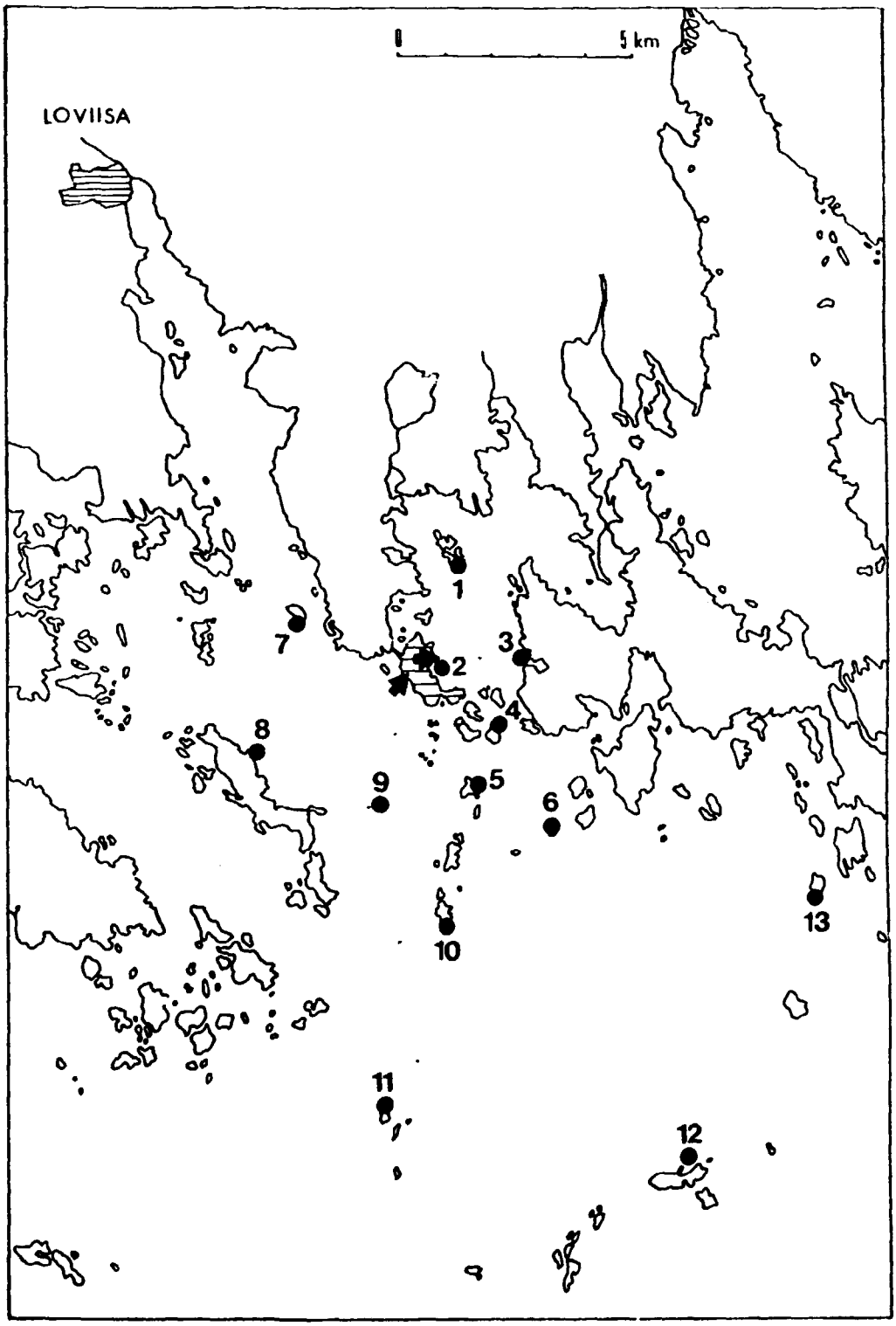

Fig. 3. Sampling stations in the sea area around Loviisa. The cooling water intake and outlet are marked with arrows.

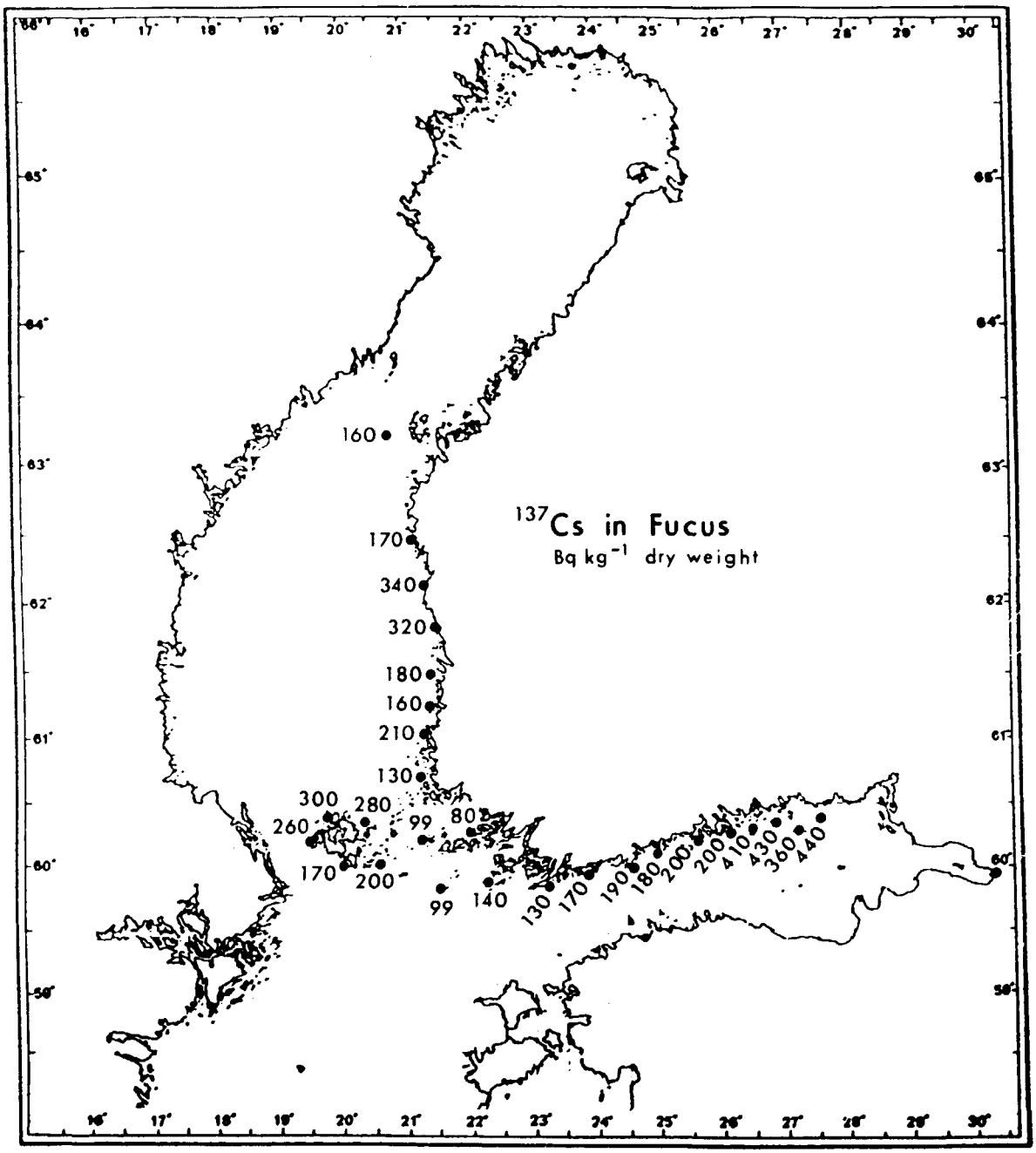

Fig. 4. ^{137}Cs in *Fucus vesiculosus* (Bq kg^{-1} dry weight) along the Finnish coast in 1987.

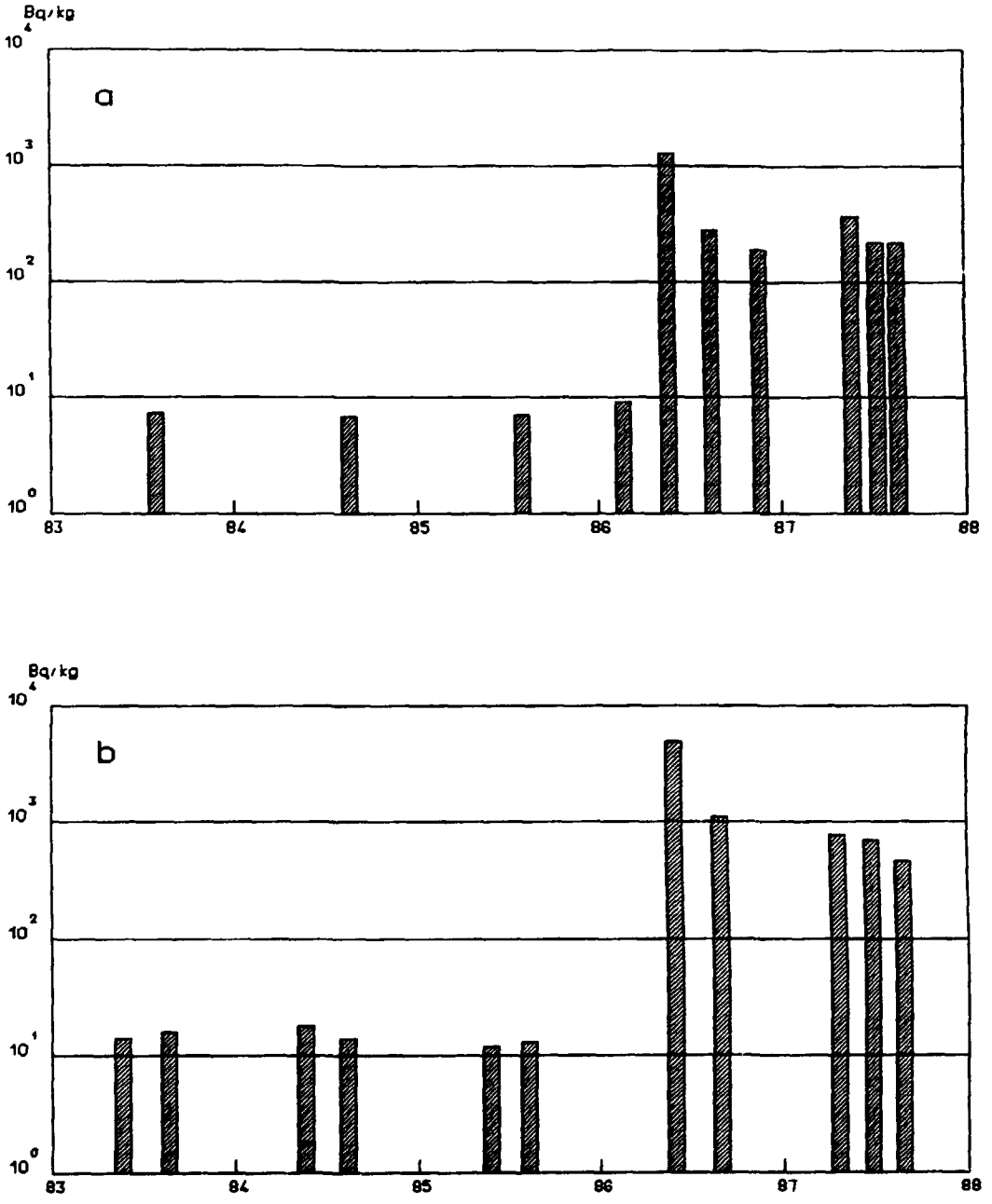

Fig. 5. ^{137}Cs in *Fucus vesiculosus* (Bq kg^{-1} dry weight) at the Olkiluoto sampling station 9 (a) and at the Loviisa sampling station 2 (b) in 1983-1987.

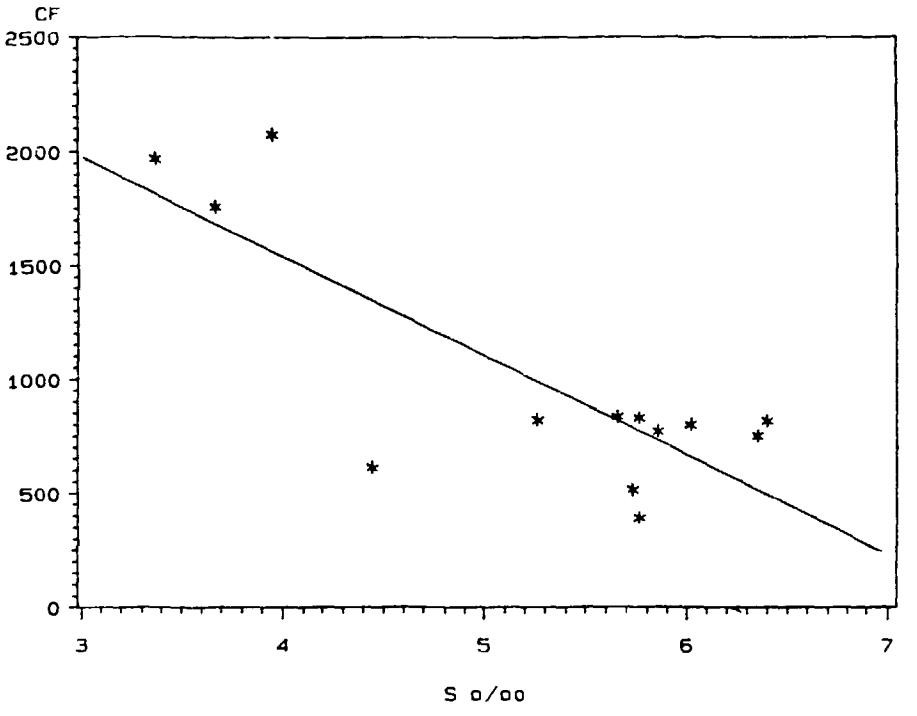

Fig. 6. The concentration factor (on dry weight basis) of ^{137}Cs in *Fucus vesiculosus* as the function of salinity.

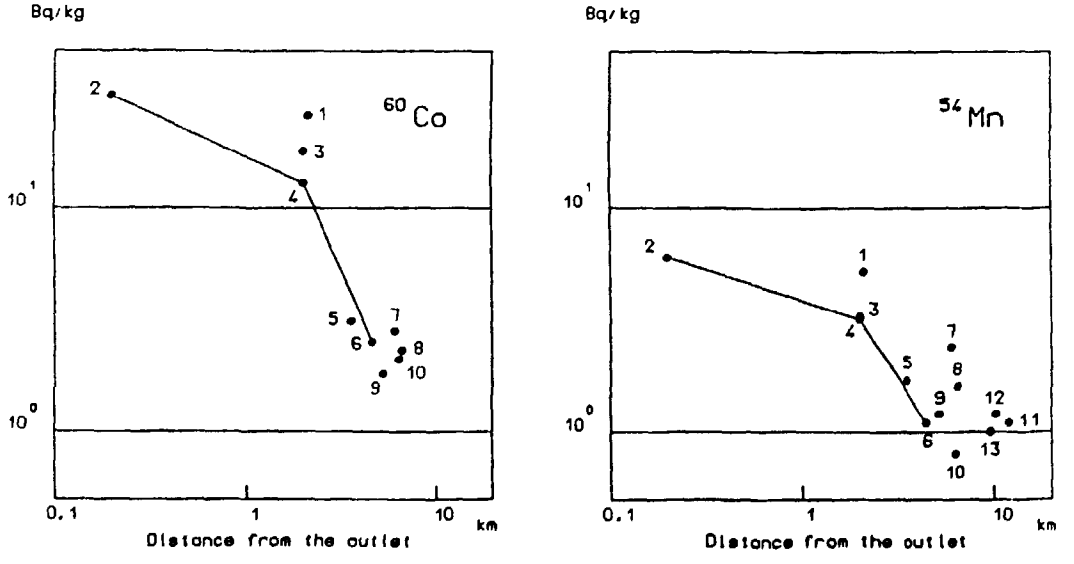

Fig. 7. The concentration of ^{60}Co and ^{54}Mn in *Fucus vesiculosus* in relation to the distance from Loviisa power station. The broken line indicates the direct route out from the discharge area.

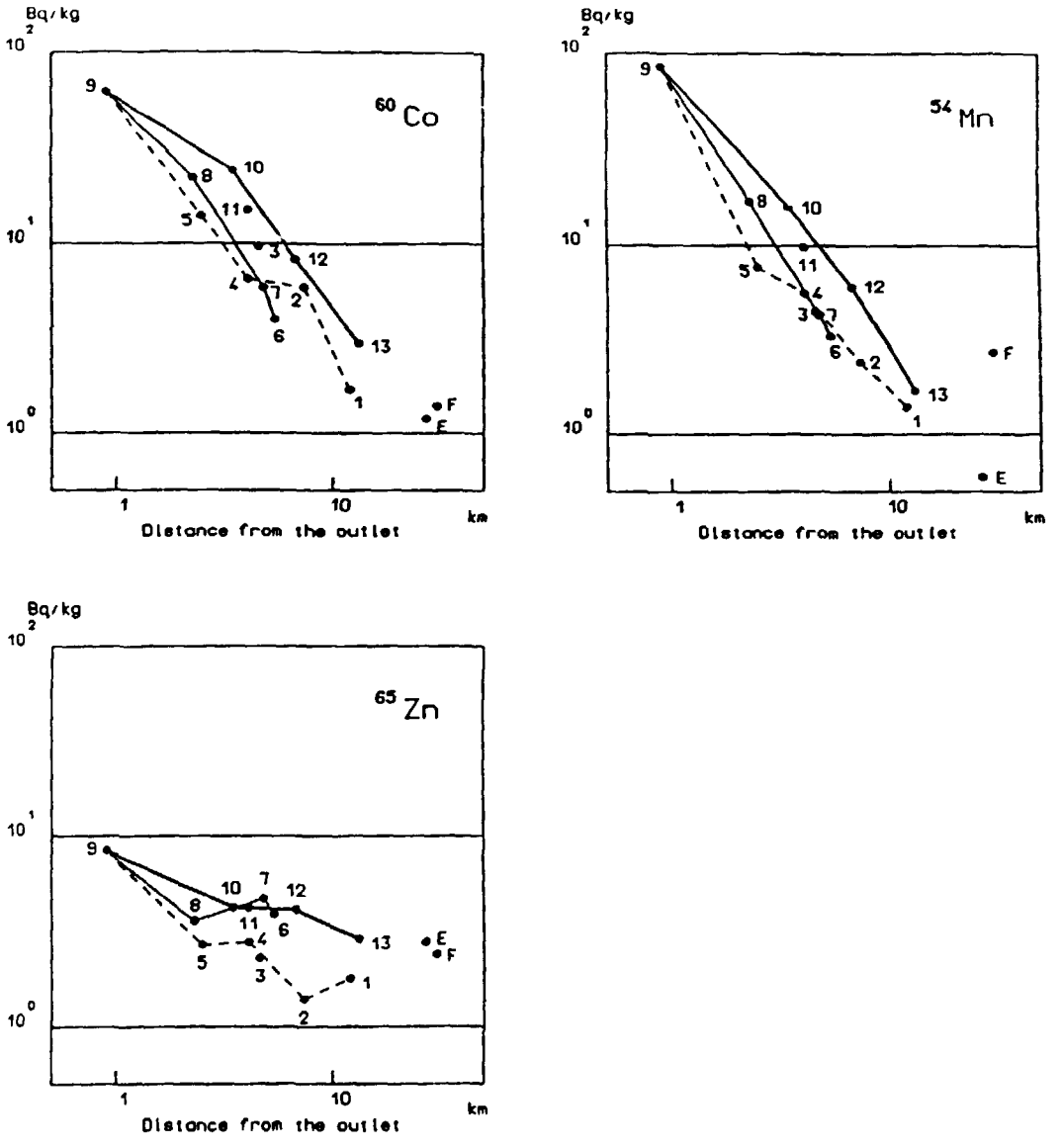

Fig. 8. The concentration of ^{60}Co, ^{54}Mn and ^{65}Zn in *Fucus vesiculosus* in relation to the distance from Olkiluoto power station. The thick line indicates the spreading direction to the north, the thin line to the west and the dotted line to the southwest.

Table I. Sampling data.

Coastal stations

Code	Municipality, tract, place, coordinates	Sampling date	Sampling depth m	Character of bottom	Water salinity ‰
A	Mustasaari, Norrskär, Norrberget NW, 63°15.1'N, 20°38.9'E	12.08.87	1-3	sand and stones	4.45
B	Närpiö, Nämpnäs Öskata NW, 62°28.5'N, 21°08.3'E	11.08.87	1-3	stony	5.77
C	Kristiinankaupunki, Skaftung, Kummelgrund N, 62°09.2'N, 21°19.0'E	11.08.87	1-3	sand and stones	5.54
D	Merikarvia, Krookanlahti Jukola E, 61°50.7'N, 21°28.4'E	11.08.87	1	clay and stones	5.27
E	Luvia, Säppi, Säppi E, 61°28.7'N, 21°22.3'E	18.08.87	2-3	rocky	5.58
F	Uusikaupunki, Pyhämaa, Pujo SW, 60°59.7'N, 21°15.8'E	7.08.87	2	sand and stones	6.04
G	Kustavi, Isokari, Hamskeri N, 60°40.9'N, 21°08.6'E	6.08.87	2	stony	6.36
H	Vårdö, Västra Simskäla, Norrgård S, 60°20.2'N, 20°18.7'E	24.08.87	1-2	sand and stones	6.11
I	Geta, Isaksö, Färjställe N, 60°22.3'N, 19°46.2'E	24.08.87	1	rocky	5.86
J	Eckerö, Storby, Berghamn N, 60°13.6'N, 19°32.3'E	25.08.87	1-2	sand and stones	6.27
K	Lemland, Järsö, Gloskär N, 60°00.5'N, 19°57.3'E	24.10.87	-	-	-
L	Föglö, Sommarö, Havsklippan S, 60°00.9'N, 20°35.5'E	25.08.87	2	stony	6.59
M	Houtskari, Fiskö, Fiskö NW, 60°12.1'N, 21°13.0'E	6.08.87	3	sand and stones	6.51
N	Nauvo, Seili, Orhisaari E, 60°16.5'N, 22°00.0'E	6.08.87	1-2	sand and stones	6.03
O	Korppoo, Jurmo, Killingharu S, 59°49.3'N, 21°33.0'E	5.08.87	2	rocky	6.54
P	Dragsfjärd, Rosala, Fjärdskär E, 59°53.2'N, 22°23.6'E	5.08.87	3	stony	6.27
Q	Hanko, Tvärminne, Långskär SE, 59°49.0'N, 23°16.0'E	4.08.87	2	rocky slope	6.41
R	Tammisaari, Gästans, Stora Rävskär N, 59°54.5'N, 23°47.0'E	4.08.87	2	rocky slope	6.24
S	Porkkala, Stora Mickelskären, Salgrund N, 59°58.6'N, 24°32.9'E	4.08.87	2-3	rocky slope	5.99
T	Helsinki, Katajaluoto, Tu:tkobben N, 60°05.9'N, 24°57.8'E	4.08.87	2-3	stony	5.77
U	P:.voo, Onas, Rönnskär NE, 60°11.3'N, 25°34.6'E	18.09.87	2-3	rock and stones	5.47
V	Porvoo, Pellinki, Lökskär NE, 60°12.5'N, 26°04.5'E	18.09.87	2	rock and stones	4.91
W	Pyhtää, Kaunissaari, Pienkari E, 60°20.6'N, 26°47.6'E	23.06.87	3	sand and stones	3.52
X	Kotka, Haapasaari, Veitkari SE, 60°16.0'N, 27°14.6'E	23.06.87	3	rock and boulders	3.99
Y	Vehkalahti, Tammio, Ulko-Tammio E, 60°20.7'N, 27°28.3'E	23.06.87	3	rock and boulders	3.67

Table I cont.

The Olkiluoto area

Code	Sampling location (cf. Fig. 2)	Distance from the outlet/km[a]	Sampling date	Sampling depth m	Character of bottom	Water salinity ‰
1	Iso Pietari S	12.0 (N)	2.9.87	2	stony	5.83
2	Uskalinmaa, Päärkarta S	7.4 (N)	2.9.87	2	stony	5.63
3	Iso Frouvankari S	4.6 (NE)	3.9.87	2	sand and stones	5.13
4	Iso Pyrekari S	4.1 (N)	3.9.87	3	sand and stones	5.73
5	Iso Susikari NE	2.5 (NW)	3.9.87	2	stony	5.71
6	Kalla, Vähä-Siilið E	5.4 (NW)	2.9.87	2	stony	5.74
7	Etelăriutta E	4.8 (W)	2.9.87	2	stony	5.79
8	Kalliopöllä N	2.3 (W)	19.8.87	1-2	sand and stones	5.96
9	Kaalonpuhdin matalikko	0.9 (W)	19.8.87	1-2	sand and stones	5.66
10	Reimargrund N	3.5 (SW)	3.9.87	1-2	stony	5.71
11	Iso Kivikkokari NE	4.1 (W)	19.8.87	1-2	stony	5.96
12	Nurmes, Vähäkrunni N	6.8 (SW)	2.9.87	2-3	stony	5.87
13	Rauma, Kylmäpihlaja N	13.2 (SW)	2.9.87	3	stony	5.92

[a] measured along the water route

The Loviisa area

Code	Sampling location (cf. Fig. 3)	Distance from the outlet/km[a]	Sampling date	Sampling depth m	Character of bottom	Water salinity ‰
1	Smedsholmarna S	2.1 (N)	25.6.87	2	boulders	3.70
2	Halkokari S	0.2 (SE)	25.6.87	2	boulders	4.01
3	Gäddbergsö, Bölsviken NW	2.0 (E)	25.6.87	2	stones	3.95
4	Myssholmen NE	2.0 (SE)	25.6.87	2	rocky slope	4.05
5	Stora Rövarn E	3.5 (S)	25.6.87	3	stones	3.97
6	Lilla Djupberget N	4.5 (SE)	25.6.87	2	stones	3.37
7	Svartholm S	6.0 (W)	25.6.87	1-2	stones	3.94
8	Hudö, Tällholmen E	6.5 (SW)	25.6.87	1-2	sand and stones	3.91
9	Kuggen E	5.2 (SW)	25.6.87	2	sand and stones	4.10
10	Yttre Täktarn S	6.3 (S)	24.6.87	3	stones	3.88
11	Storskarven N	10.3 (S)	24.6.87	3	stones	3.88
12	Orrengrund, Norrhället N	12.0 (SE)	24.6.87	3	rock and stones	3.75
13	Boistö S	9.6 (SE)	24.6.87	2-3	stones	2.44

[a] measured along the water route

Table II. Biological notes on the abundance, shape and state of Fucus vesiculosus at different sampling stations.

Sampling station	Fresh wt. g m^{-2}	dry wt. / fresh wt.	Abundance of Fucus	Shape and state of Fucus
A	820	0.20	Single tufts here and there. Small-sized and narrow thalli, clean.	
B	2170	0.22	Belt-forming, relatively abundant. Clean and healthy.	
C	230	0.17	Sparse. Small-sized, brittle and dirty.	
D	-	-	Scanty. Small-sized, brittle and dirty.	
E	3060	0.15	Relatively abundant. Larger tufts, almost clean.	
F	1480	0.15	Evenly everywhere, coverage 50 %. Covered by epiphytes.	
G	5950	0.18	Uniform zone. Partly covered by green algae.	
H	9690	0.21	Relatively abundant. Tall and fertile thalli, epiphytes.	
I	4340	0.17	Relatively abundant. Tall and fertile thalli, epiphytes.	
J	14290	0.16	Uniform zone. Tall and dense bushes. Healthy.	
K	notes are lacking			
L	2190	0.18	Moderately. Tall, fertile, but bad-looking, covered by epiphytes.	
M	2220	0.21	Uniform zone. Relatively small, clean and healthy.	
N	380	0.13	Scantily. Covered by green algae.	
O	8190	0.17	Uniform zone. Tall, clean and healthy thalli.	
P	3030	0.15	Scantily. Tall thalli covered by epiphytes.	
Q	11350	0.14	Uniform zone. Tall and healthy.	
R	930	0.27	Sparse. Tall and fertile thalli, epiphytes.	
S	7960	0.19	Uniform zone. Clean and healthy.	
T	3640	0.21	Abundantly. Relatively clean.	
U	6790	0.15	Uniform zone. Clean and healthy.	
V	8320	0.15	Uniform zone. Clean and healthy.	
W	2640	0.16	Relatively abundant. Small-sized, but clean and healthy.	
X	3380	0.15	Relatively abundant. Small-sized, but clean and healthy.	
Y	2080	0.14	Relatively abundant. Small-sized, but clean and healthy.	
Olkiluoto				
1	1020	0.16	Abundantly. Flat and small-sized thalli, clean.	
2	1350	0.20	Moderately. Small-sized, clean.	
3	1220	0.17	Single tufts here and there. Relatively clean.	
4	2910	0.19	Evenly on the stones, coverage 50 %. Brittle but clean.	
5	4390	0.18	Moderately on stones. Relatively clean and healthy.	
6	2600	0.16	Uniform zone. Clean and healthy.	
7	7550	0.17	Abundantly on stones. Relatively clean.	
8	6120	0.16	Relatively abundant. Tall and relatively clean tufts.	
9	1280	0.18	Sparse. Small-sized and brittle, covered by Membranipora.	
10	6480	0.17	Uniform zone. Clean and healthy.	
11	4260	0.18	Relatively abundant. Relatively clean.	
12	8420	0.18	Uniform zone. Tall, light, clean thalli.	
13	2240	0.19	Uniform zone. Clean and healthy.	
Loviisa				
1	2090	0.19	Moderately. Small, brittle 'cauliflower' thalli, epiphytes.	
2	820	0.15	Sparse. Small, dark, brittle 'cauliflower' thalli, epiphytes.	
3	2060	0.18	Moderately. Small-sized, dark and brittle, covered by epiphytes.	
4	1870	0.19	Relatively abundant. Small, dark and brittle thalli.	
5	1040	0.19	Moderately. Small-sized, covered by epiphytes.	
6	3030	0.14	Relatively abundant. Relatively clean and light.	
7	2070	0.15	Moderately. Covered by epiphytes.	
8	4130	0.16	Abundantly. Tall, brittle and dark, plenty of epiphytes.	
9	2780	0.13	Abundantly on stones. Covered by epiphytes.	
10	6190	0.15	Uniform zone. Dense and good-looking.	
11	5360	0.15	Uniform zone. Relatively clean and light.	
12	1180	0.16	Coverage 60 %. Small-sized, relatively clean.	
13	2510	0.15	Abundantly, coverage 70 %. Clean and healthy.	

Table III. ^{90}Sr, ^{238}Pu, $^{239,240}Pu$ and gamma-emitting radionuclides in *Fucus vesiculosus* (Bq kg^{-1} dry weight) along the Finnish coast. For sampling stations see Figure 1.

Sampling station	^{40}K	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{238}Pu	$^{239,240}Pu$
A	700	1.5	0	6.4	14	6	30	0[a]	60	160	0	0	0.062
B	480	0.8	0	1.2	18	7	13	0	63	170	0	0.002	0.036
C	640	1.5	0	1.5	-[b]	38	13	5.2	130	340	4	-	-
D	700	3.0	1.0	1.2	21	37	9.7	14	120	320	11	0.16	0.17
E	710	0.6	1.2	2.8	-	13	21	0	68	180	0	-	-
F	760	2.7	1.4	2.4	-	22	13	0	78	210	0	-	-
G	860	1.0	0	2.2	15	14	13	2	45	130	0	-	-
H	730	0.8	0	2.1	-	8	10	0	110	280	0	-	-
I	580	3.0	0	2	18	13	9.6	0	110	300	0	0.009	0.14
J	900	2.8	3.8	8.4	-	8	26	0	98	260	0	-	-
K	930	1.3	2.0	4.9	-	4	19	0	59	170	0	-	-
L	760	0	0	3	-	0	3	0	71	200	0	-	-
M	840	0	0	0	-	10	2.3	4	37	99	0	-	-
N	950	0	0	0	13	0	0	0	30	80	0	0	0.063
O	880	0	0	1.3	-	6	4.4	0	37	99	0	-	-
P	850	0	0	0	-	10	0.8	0	52	140	0	-	-
Q	1200	0	0	0	16	7	2.6	0	47	130	0	0	0.16
R	750	0	0	0	-	16	1.8	0	67	170	0	-	-
S	950	0	0	0	-	17	3.5	0	70	190	0	-	-
T	910	0	0	0	15	22	4.4	0	67	180	0	0	0.12
U	1000	0.4	0	0	-	14	4.7	1	72	200	0	-	-
V	880	0.7	0	1.5	-	15	6.6	1	72	200	0	-	-
W	850	1.2	0	3.8	-	30	22	0	170	430	0	-	-
X	860	1.4	0	3.2	-	30	31	0	140	360	0	-	-
Y	1100	0.6	0	2.0	22	25	25	0	170	440	0	0	0.14

[a] below the detection limit
[b] not analysed

Table IV. ^{90}Sr, ^{238}Pu, $^{239,240}Pu$ and gamma-emitting radionuclides in *Fucus vesiculosus* (Bq kg $^{-1}$ dry weight) at Olkiluoto. For sampling stations see Figure 2.

Sampling station	^{40}K	^{51}Cr	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{238}Pu	$^{239,240}Pu$
1	630	0 [a]	1.4	0	1.7	1.8	-[b]	11	16	0	53	150	3.5	-	-
2	690	0	2.4	0	5.9	1.4	-	8	9.9	0	57	160	0	-	-
3	730	0	4.5	0	9.7	2.3	-	9	10	0	71	190	0	-	-
4	650	0	5.6	0	6.5	2.8	-	13	16	0	63	170	0	-	-
5	680	0	7.7	0	14	2.7	-	8	10	0	63	170	0	-	-
6	770	0	3.3	0	4.5	3.9	20	11	19	0	62	160	0	0.011	0.054
7	900	0	4.3	0	5.9	4.7	-	15	24	0	70	190	13	-	-
8	810	0	17	1.2	22	3.6	23	13	12	0	85	230	5.4	-	-
9	660	32	85	5.8	62	8.4	19	22	17	5.6	81	220	17	-	-
10	660	0	16	0	24	4.2	-	7.3	12	0	62	170	0	-	-
11	660	0	9.8	0	15	4.2	-	16	13	0	70	190	0	-	-
12	770	0	6.0	0	8.3	4.1	-	10	19	0	58	150	0	-	-
13	760	0	1.7	0	3.0	2.9	-	14	27	0	59	150	0	-	-

[a] below the detection limit
[b] not analysed

Table V. ^{90}Sr, ^{238}Pu, $^{239,240}Pu$ and gamma-emitting radionuclides in *Fucus vesiculosus* (Bq kg^{-1} dry weight) at Loviisa. For sampling stations see Figure 3.

Sampling station	^{40}K	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{238}Pu	$^{239,240}Pu$
1	880	5.2	26	2.5	- [a]	90	15	8.3	240	610	8	-	-
2	970	6.0	32	0[b]	-	74	22	6	260	670	0	-	-
3	800	3.3	18	2.8	27	70	16	8.2	230	570	0	-	-
4	930	3.2	13	2.5	-	66	15	7.7	230	590	5	-	-
5	820	1.7	3.1	2.3	-	48	12	0	190	480	11	-	-
6	900	1.1	2.5	2.7	21	38	18	0	230	570	0	0	0.15
7	930	2.4	2.8	1.8	-	48	16	0	200	500	0	-	-
8	790	1.6	2.3	2.0	-	56	11	0	200	480	0	-	-
9	870	1.2	1.8	2.1	-	47	14	0	200	500	0	-	-
10	960	0.8	2.1	3.2	-	26	19	0	170	420	0	-	-
11	790	1.2	0	2.4	-	28	19	0	150	370	2	-	-
12	840	1.1	0	3.5	-	48	22	0	160	410	0	-	-
13	1000	1.0	0	4.0	-	3.5	29	0	190	470	0	-	-

[a] not analysed
[b] below the detection limit

Table VI. Gamma-emitting radionuclides in sea water samples (Bq m^{-3}) taken along the Finnish coast. For sampling stations see Figures 1-3.

Sampling station	^{40}K	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
A					
particulate	0[a]	0	0	3.1	7.8
soluble	1800	0	10	100	260
B	2300	0	22	170	430
D	2100	0	22	150	390
G	2800	0	0	61	169
I	2500	0	9.4	150	390
N	2300	0	0	33	100
Q	2400	0	0	61	160
T	2100	20	10	82	220
Y	1300	0	0	99	250
Olkiluoto 6	2200	0	0	120	310
Olkiluoto 9	1900	0	0	100	260
Loviisa 3					
particulate	0	0	0	1.5	2.7
soluble	1400	0	13	110	270
Loviisa 6					
particulate	0	0	0	0.7	2.6
soluble	1600	0	18	110	290

[a] below the detection limit

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