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Determination of recent sedimentation in the Gulf of Finland using ^{137}Cs

^{137}Cs
Accumulation rate
Gulf of Finland
Mixing
Sediments

^{137}Cs
Taux de sédimentation
Golfe de Finlande
Mélange
Sédiments

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ABSTRACT

Linear accumulation rates and dry-matter accumulation rates were determined using ^{137}Cs distribution in sediment cores from 98 coastal and open-sea stations from around the Gulf of Finland (the Baltic Sea). Results showed that the average linear accumulation rate varied between 0.05-1.94 (mean 0.60) cm a^{-1}, which corresponds to a dry-matter accumulation rate of 0.01-0.30 (mean 0.15) g cm^{-2} a^{-1}. Accumulation rates were high in recent mud sediments, especially near river outlets. The highest rates were found at inshore stations near Kotka town. Peak ^{137}Cs activities in cores from the whole study area varied between 0.04-2.4 Bq g^{-1} wet weight. The highest activities were found in areas most affected by fallout from the 1986 Chernobyl accident, and corresponded to the overall areal distribution of ^{137}Cs in the soil; but the areal distribution of ^{137}Cs in the sediments was also caused by the discharge of sedimenting particulate material from land. Total Chernobyl fallout in the area was between 1.4-80.5 (mean 21) kBq m^{-2}. Mixing of sediment strata was considerable in the uppermost sediment layers of many soft sediments, as indicated by the width of the ^{137}Cs peak in the cores. The ^{137}Cs technique can be used successfully in the Gulf of Finland because of high radiocaesium activities and the high accumulation rates. With the data obtained, the suitability of the stations for chronological sampling and monitoring was evaluated, and several new sediment stations that could be used for monitoring were identified.

RÉSUMÉ

Utilisation du ^{137}Cs pour déterminer la sédimentation récente dans le golfe de Finlande.

Le taux de sédimentation linéaire et l'intensité de l'accumulation de matière sèche ont été mesurés à l'aide de la répartition du ^{137}Cs dans les carottes sédimentaires prélevées en 98 stations du golfe de Finlande (Mer Baltique). Le taux de sédimentation linéaire varie de 0,05 à 1,94 g cm^{-2} a^{-1}, (moyenne: 0,60 g cm^{-2} a^{-1}), ce qui correspond à une accumulation de matière sèche comprise entre 0,01 et 0,30 g cm^{-2} a^{-1}, (moyenne: 0,15 g cm^{-2} a^{-1}). L'intensité de l'accumulation est élevée, surtout à proximité des bassins fluviaux, avec un maximum vers la ville de Kotka, sur la côte finlandaise. L'activité maximale du ^{137}Cs dans les carottes sédimentaires varie entre 0,04 et 2,4 Bq g^{-1} dans la matière fraîche. Les activités les plus élevées sont observées dans les régions côtières les plus exposées aux retombées de l'accident de Tchernobyl en 1986; elles sont en accord avec la répartition générale du ^{137}Cs sur terre. La précipitation totale du ^{137}Cs en provenance de Tchernobyl se situe entre 1,4 et 80,5 kBq m^{-2}, avec une moyenne de 21 kBq m^{-2}. Les fortes valeurs de l'accumulation et de l'activité dans les bassins marins peu profonds indiquent que la répartition géographique de ces grandeurs est soumise à la précipitation, mais aussi aux décharges fluviales. Les couches supérieures sont considérablement mélangées dans la plupart des sédiments souples, comme l'indique la largeur de la bande d'activité maximale du ^{137}Cs dans la carotte. La technique ^{137}Cs est fructueuse dans le golfe de Finlande, en raison de l'activité élevée du radiocésium et du taux d'accumulation important. Les données obtenues permettent d'évaluer l'intérêt des stations étudiées pour la surveillance de l'environnement marin; plusieurs nouveaux sites ont été identifiés.

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INTRODUCTION

The selection and study of representative net sedimentation areas is an essential task in the work of monitoring human impact on the marine environment, especially where sedimentation has an important role in the mass budget, as in the case of the Baltic Sea. When there is a need to relate the concentration of pollutants in sediments to time and mass-balance calculations, knowledge about accumulation rates is also essential. Radioactive elements such as ^{210}Pb (Krishnaswami *et al.*, 1971; Häsänen, 1977), $^{239+240}$Pu (Livingston and Bowen, 1979; Jaakkola *et al.*, 1983; Crusius and Anderson, 1995), ^{228}Th/^{232}Th (*e.g.* Koide *et al.*, 1973), ^{137}Cs and non-radioactive tracers (*e.g.* Hg and organic carbon) are often used to determine recent sediment chronologies and growth of sediment thickness. The common requirement for all these applications is either a constant fallout rate or a pulsed supply of the tracer material.

To overcome some of the limitations of traditional ^{210}Pb dating that does not use direct γ-detection, faster methods involving artificial radioactive tracers like ^{137}Cs can be used for determining the average accumulation rates of recent sediments (*e.g.* Pennington *et al.*, 1973; Ritchie *et al.*, 1973; Robbins and Edgington, 1975; Robbins *et al.*, 1977). An additional advantage of ^{137}Cs dating is that radioactive decay can be monitored without destroying the sample, thereby allowing the same sample to be used for other analyses. Moreover, the equipment needed to measure ^{137}Cs activity can be used on board, which makes it possible to estimate recent accumulation rates during sampling operations (Kyzyurov *et al.*, 1994). According to Ritchie *et al.* (1973) and Davis *et al.* (1984), the usefulness of ^{137}Cs in tracing erosion processes and in dating recent deposition is based on four premises: (i) deposition of ^{137}Cs reflects atmospheric fall-out rate; (ii) most ^{137}Cs is adsorbed tightly on fine suspended material; and becomes part of the depositing material, (iii) ^{137}Cs is not actively concentrated into a chemically distinct layer by diagenetic processes; and iv) the radionuclide remains immobile in the sediment after deposition.

The most recent source of radioactive fallout was the Chernobyl nuclear power plant accident on 25 April, 1986, which released approximately 1.3×10^{16} Bq of gamma-emitting ^{137}Cs ($T_{1/2} = 30.2$ years, gamma energy 661.63 keV) into the atmosphere (Buesseler *et al.*, 1987). Radioactive air masses reached the Gulf of Finland and adjacent sea areas 24 hours after the accident and contamination occurred during the following five days. Most of the ^{137}Cs fallout reached ground and sea level in the form of wet precipitation (Finnish Centre for Radiation and Nuclear Safety, 1986); the Gulf of Finland also received ^{137}Cs by river transport. This most recent introduction of ^{137}Cs left a clear stratigraphic marker in the sediments of the Baltic Sea (Perttilä and Niemistö, 1993; Kyzyurov *et al.*, 1994). In sediment basins, the radioactive layer is buried at depths that correspond to the accumulation rate and the time taken for radioactive particles to be transported from point of deposition, and is dispersed vertically according to mixing intensity. Because the accident occurred in spring, the radioactive layer was rapidly covered with material from plankton blooms and clayey, river-derived material. In the latter half of the 1980s the density of benthic animals in the Gulf of Finland was low compared to the present situation (Andersin and Sandler, 1991). Together, these conditions make the Gulf of Finland a suitable area for sedimentation studies using ^{137}Cs.

Study area

The Gulf of Finland is a shallow (mean depth 38 m) north-eastern extension of the Baltic Sea's Gotland Basin (*see* Fig. 1). Covering 29 600 km^2 and with a total water volume of about 1 100 km^3, the Gulf is fed in the east by three significant rivers, the Neva, the Kymi and the Narva (*see* Fig. 1), and has a total, annual river inflow of about 100-125 km^3 a^{-1}. The Gulf of Finland, sometimes regarded as a large estuary, is nutrient-rich (*e.g.* Pitkänen, 1994) compared to other Baltic Sea areas. Salinity is low and increases in the surface waters from 0 in the east to 6 in the west. The structure and topography of the sea bed may be described as mosaic, being characterized by a varying distribution of bottom types, especially along the northern coast, where outcrops of rock alternate with till and clay

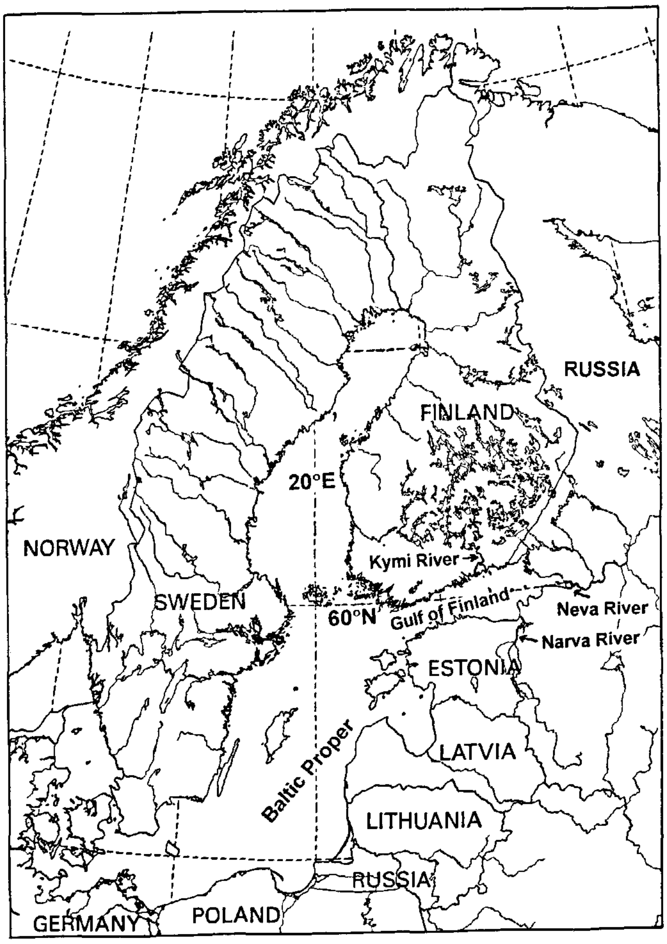

Figure 1

Location of study area in northern Europe.

sediments, which usually fill the deeper parts. Basins with mud accumulation are generally small (*e.g.* Logvinenko *et al.*, 1978; Winterhalter *et al.*, 1981). Cambrian and Ordovician sedimentary rock areas of the southern and eastern parts are characterized by larger sedimentation basins. These basins occur along the Estonian coastline (Winterhalter *et al.*, 1981) and in the eastern Gulf. In the Gulf of Finland, sedimentation processes tend to fill basins with recent, soft sediments and may be described as "basin-filling" (Winterhalter, 1992).

In the Gulf of Finland, there is a general eastward flow of surface water from the Baltic proper along the Estonian coastline. This factor, together with the limited effect of rivers on the Estonian coast, also contributes to the differences between the character of sedimentation on the Estonian side and the Finnish side, where surface water flows westwards and the effect of river inflow is more pronounced. In the deepest basins (up to 123 m), found on the Estonian side, bottom water is also derived from the waters of the Baltic proper. The oxygen content of the water covering these deep basins is sometimes very low, and this is reflected in a low abundance of benthic fauna (Andersin and Sandler, 1991).

The material deposited in the Gulf of Finland is a mixture composed of: (i) formerly deposited and latterly resuspended sediments; (ii) material of autochthonous origin (Perttilä and Niemistö, 1993); and (iii) river-transported and allochtonous material. Algal blooms are stimulated by high nutrient concentrations in spring and early autumn and produce a large proportion of the organic deposition.

For the Gulf of Finland, data on accumulation rates and dry-matter accumulation rates, on the extent of bioturbation and on the spatial distribution of ^{137}Cs are still scarce. In fact, sedimentation data are scarce for the whole Baltic Sea area. Values for ^{137}Cs vertical distribution in the sea floor have been reported from the Gulf of Finland (Ilus *et al.*, 1993; Perttilä and Niemistö, 1993; Kyzyurov *et al.*, 1994), but no accumulation rate estimates have been derived from these results. The data have shown only that, in most cases, maximum ^{137}Cs activity occurs in the uppermost 10 cm. Estimates on the effect of the mixing of strata by bioturbation would be of interest, especially at the present time, as bottom water oxygen content has recently increased in the Gulf of Finland (Perttilä *et al.*, 1995), stimulating bioturbation by benthic animals.

Attempts have been made to evaluate the mean rate of sedimentation for the entire Gulf of Finland. Salo *et al.* (1986) derived a mean rate of 0.4 cm a^{-1} by balancing the known inputs and outputs of the radionuclides ^{90}Sr and ^{137}Cs. Perttilä *et al.* (1995) arrived at 0.16 cm a^{-1} when doing the same with their phosphorus budget calculations. In this study, we have used vertical distribution of ^{137}Cs activity in an effort to calculate average post-Chernobyl

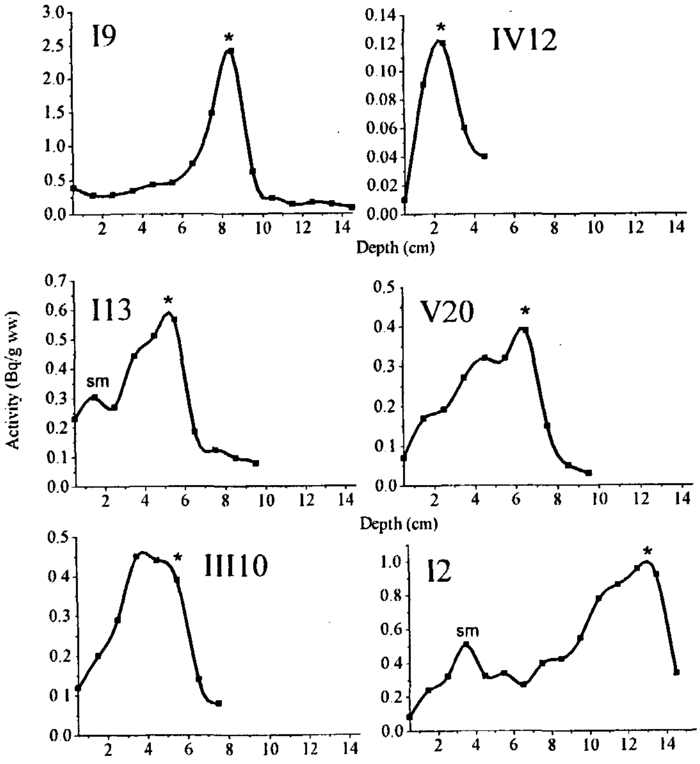

Figure 2

Sub-types of ^{137}Cs profiles. The selected stations are: I9, IV12, I13, V20 (F41), III10 (GF5) and I2. The layer used for accumulation rate and dry-matter accumulation rate calculations is marked with an asterisk.

accumulation rates in the central and eastern parts of the Gulf. To estimate roughly the extent of sediment mixing, we observed the curve shape of vertical ^{137}Cs distribution. The specific activities and the total quantities of ^{137}Cs observed were used to obtain an overall picture of the spatial distribution of Chernobyl-derived ^{137}Cs. To meet the need for a rapid survey method, most results are based on wet-weight of samples, weighed on board. The data were also used to estimate the suitability of the sampling stations for chronological sampling and sediment monitoring.

MATERIALS AND METHODS

Recent sediment samples were collected at areas of active deposition, *i.e.* from soft mud bottoms. In the Kotka area, recent deposits were selected with the help of an accurate bottom deposit map (Häkkinen and Åker, 1991). Sampling was performed during cruises with: 1) the Finnish R/V *Aranda* (August 1992; ICES-HELCOM Sediment Base-line Study, June-July 1993 and May-June 1994); 2) the Finnish R/V *Muikku* (August 1992); 3) the Russian R/V *Professor Multanovskiy* (June 1993); 4) the Russian R/V *Persey* (UNESCO-IOC-HELCOM Baltic Floating University, August 1994); and 5) the Russian R/V *Professor Logachev* (June 1995). Before sampling, the structure of the sediment was confirmed with echosounders.

Positioning on the different vessels was based on (referring to the numbering above): 1) and 2) Differential Global Positioning System (DGPS), using Finnish co-ordinate datum (KKJ) with better than ±5 m error; 3) and 5) GPS, using WGS-84 co-ordinate datum with better than ±50 m error; and 4) Russian navigation system, with approximately ±100 m error. The difference between KKJ and WGS-84 co-ordinates in the study area is: $\mathrm{LAT_{WGS\text{-}84}} = \mathrm{LAT_{KKJ}} + 0.00017°$, $\mathrm{LON_{WGS\text{-}84}} = \mathrm{LON_{KKJ}} - 0.00317°$. See Tables 1*a*, *b* for individual station information.

The sediments were sampled using three different gravity corers with internal diameters of 50 mm (Niemistö, 1974), 80 mm (Gemini corer) and 100 mm (stations V22-V46). Cores were sectioned into 1 cm sub-samples, and stored at −20 °C until analysed. The areas sampled were: I) Ahvenkoski-Kotka-Haapasaari (18 stations); II) Vyborg Bay (12 stations); III) Luzhskaya and Koporskaya Bights (10 stations); IV) Ihasalu and Tallinn Bays (12 stations); and V) open-sea stations in the middle and eastern Gulf of Finland (46 stations). For locations refer to Figures 3-7.

After weighing sediment sub-samples, the gamma spectra of the samples were measured using an UMKA-type spectrometer (2π geometry, 1024-channel NaI/Tl scintillation detector, 80 × 80 mm and 150 × 100 mm crystals; manufactured by the Radiochemical Laboratory of the Krylov Shipbuilding Institute, St. Petersburg, Russia). Exposure times were of 30 or 10 min, depending on the detectors counting efficiency. Background radiation was measured using the same acquisition time. Some of the samples from the open-sea area were analysed at the Geological Survey of Finland, using an EG&G Ortec ACE$^{\mathrm{TM}}$-2K spectrometer with a 4″ NaI/Tl detector; and at the Technical Research Centre of Finland, Espoo, using a Canberra pulse-height analyzer and a well- type NaI/Tl scintillation detector. Only the relative activity distribution was determined with the EG&G's instrument. Instruments were not intercalibrated.

Using the smaller detector (UMKA, 80 × 80 mm), background caesium activity was measured at 3.2 ± 1.1 Bq. This means that the maximum activity in each core was at least two times higher than the background activity. The error for final activitity in layers with low activity can be substantial, but, for the sake of simplicity, error bars have been omitted from the figures describing ^{137}Cs profiles and spatial activity distribution. Over 90 % of the samples contained at least three times the background activity in their maximum ^{137}Cs layer. The activity measurement was calibrated using a certified (90 g) ^{137}Cs standard of initial 20.20 Bq g^{-1} activity. In cores taken with the 80 mm ∅ corer, the average weight of the maximum activity layer was approximately 75 g (ww) and the analytical detection limit, with a 30 min exposure, was 0.06 Bq g^{-1} (1.5 × background radiation). Using data on background and sample measurement reproducibility, the error of activity for an average-weight sample was estimated to be ±30 % within 0.06-0.07 Bq g^{-1}, ±20 % within 0.07-0.1 Bq g^{-1}, ±10 % within 0.1-0.2 Bq g^{-1}, ±7 % within 0.2-0.5 Bq g^{-1} and <±4 % at over 0.5 Bq g^{-1}. The error for the maximum activity in cores is generally small, not more than 10 %. Exceptions were stations I7, I17, II9, IV1, IV3, IV8, IV10, IV11 and V1-V4, with a 10-20 % error in their maximum activity. In the case of stations V22-V46, which were sampled with the largest corer and measured using the larger detector, the error in ^{137}Cs maximum was only 10 % or less and the corresponding detection limit 0.03 Bq g^{-1} ww.

After the activity measurement, part of the samples were dried and dry-weight was determined. Some samples were also analysed for total carbon (TC) using UNCARBO IV equipment. At stations I17, I18, II11, II12, V6 and V7, only every second slice was measured and accumulation rate results from these locations are less accurate. Energy peaks were integrated using a PC programme, and the specific activity of the ^{137}Cs nuclide was determined for each area respectively. Specific activity is expressed as:

$$A_s = (A - A_B)/(C_e t m) \qquad (1)$$

where A_s = specific activity (Bq g^{-1} dw or ww), A = area of the ^{137}Cs peak, A_B = area of the background ^{137}Cs peak, C_e = instrument counting efficiency (0.026 or 0.137), t = time of measurement (s), m = weight of sample (g).

Activity results did not need to be corrected for decay, since measurements were made directly after sampling. Therefore, the activities reflect the 1994-1995 levels. Total activity per unit area of cores was determined in the post-Chernobyl section. The vertical position of the radiocaesium maximum within each core was determined and used as a marker in accumulation rate and dry-matter accumulation rate calculations. In most of the cores, radiocaesium activity decreased abruptly downwards from the maximum layer. In the few cases where the decrease was less pronounced, or occurred after the ^{137}Cs

Table 1*a*

*Properties of stations. ST = station, B = bottom depth (m), LAT(N) = latitude (degrees, north), LON(E) = longitude (degrees, east), NAV = navigation system used (D = DGPS with KKJ co-ordinates, G = GPS with WGS-84 co-ordinates, R = Russian co-ordinates), W = peak broadness, v = accumulation rate (cm a^{-1}). S = dry-matter accumulation rate (g cm^{-2} a^{-1}), TC = total carbon in 0-1 cm layer (%), dw% = 0-1 cm dry-weight content (%), flag = suitability of station for chronological monitoring (# = questionable, * = useful, ** = good, *** = very good). N.D. = no data.*

ST	B	LAT (N)	LON (E)	NAV	W	v'	S	TC	dw %	flag
I1	29	60.3317	26.5908	D		0.56	0.08	7.3	7.5	**
I2	15	60.4502	26.9740	D	Wide	1.55	0.30	7.0	4.7	*
I3	20	60.4263	26.9400	D	Wide	1.42	0.30	8.2	10.1	*
I4	27	60.4052	26.8915	D	Sharp	0.31	0.08	4.7	4.9	*(*)
I5	32	60.4063	26.8125	D	Wide	0.93	0.12	6.9	4.9	**
I6	33	60.3897	26.7338	D	Wide	1.18	0.18	6.9	9.7	*
I7	39	60.3737	26.7463	D	Sharp	0.31	0.06	N.D.	4.6	*(*)
I8	35	60.3508	26.7270	D	Wide	1.30	0.16	12.7	1.7	*
I9	20	60.4010	26.9548	D		1.05	0.19	N.D.	5.3	***
I10	24	60.3802	26.9700	D	Wide	1.30	0.14	9.8	1.9	**
I11	40	60.3298	26.8922	D		0.80	0.10	9.2	5.8	**
I12	40	60.3287	27.0232	D	Sharp	0.43	0.06	9.7	5.5	**
I13	45	60.3355	27.1143	D		0.68	0.11	14.0	5.2	**
I14(XV1a)	63	60.2502	27.2480	D	Sharp	0.56	0.06	8.5	5.0	**
I15(XV1b)	62	60.2388	27.2590	D		1.20	0.15	10.7	4.4	***
I16	10	60.4050	26.4917	G		1.94	N.D.	N.D.	N.D.	N.D.
I17	51	60.3885	27.2922	D		0.08	0.01	N.D.	1.7	#
I18	60	60.1933	27.1267	D		1.04	0.16	N.D.	3.3	**
II1	30	60.4688	28.2370	D		0.68	0.08	8.8	6.4	**
II2	40	60.4522	28.3138	D	Wide	0.93	0.10	9.5	5.9	**
II3	31	60.5118	28.3403	D		1.05	0.14	9.9	6.6	**
II4 (F38)	27	60.4968	28.4377	D	Sharp	0.80	0.13	7.0	7.7	**(*)
II5	25	60.5667	28.3712	D	Sharp	0.43	0.11	7.4	6.9	**
II6	10	60.6485	28.6147	D		N.D.	N.D.	5.3	N.D.	N.D.
II7	14	60.6705	28.6378	D		N.D.	N.D.	6.1	N.D.	N.D.
II8	14	60.5923	28.5048	D		0.93	N.D.	5.6	N.D.	N.D.
II9	16	60.5685	28.5255	D		N.D.	N.D.	6.0	N.D.	N.D.
II10	22	60.5502	28.5233	D		0.80	0.09	8.6	7.2	**
II11	22	60.4333	28.2833	D		1.36	0.22	N.D.	2.7	**(*)
II12	25	60.5667	28.3667	D		0.40	0.06	N.D.	2.8	*(*)
III1	22	59.9167	28.8333	R	Sharp	0.42	N.D.	N.D.	N.D.	**
III2	27	59.9167	28.7500	R	Sharp	0.42	N.D.	N.D.	N.D.	**
III3	28	59.8750	28.5833	R	Sharp	0.42	N.D.	N.D.	N.D.	**
III4	37	59.9583	28.1583	R	Sharp	0.18	N.D.	N.D.	N.D.	#
III5	34	59.9183	28.1717	R	Sharp	0.30	N.D.	N.D.	N.D.	*
III6	30	59.8967	28.1850	R		0.67	N.D.	N.D.	N.D.	**
III7	23	59.8750	28.1667	R		0.91	N.D.	N.D.	N.D.	**
III8	22	59.8000	28.1767	R	Wide	0.91	N.D.	N.D.	N.D.	*
III9	54	59.9592	28.1453	G		0.07	N.D.	N.D.	N.D.	N.D.
III10(GF5)	24	59.7585	28.2368	D		0.49	0.10	N.D.	9.5	**
IV1	71	59.5595	25.0493	D		0.06	0.09	2.4	37.1	#
IV2	59	59.5410	25.0470	D	Sharp	0.31	0.17	2.4	30.0	*(*)
IV3	43	59.5265	25.0798	D	Sharp	0.31	0.22	2.0	36.5	*
IV4	26	59.5055	25.1313	D	Sharp	0.31	0.17	2.8	33.0	*(*)
IV5	94	59.5802	24.9612	D		0.43	0.12	3.3	16.8	**
IV6	99	59.5802	24.9173	D		N.D.	N.D.	N.D.	N.D.	N.D.
IV7	87	59.5857	24.9612	D		N.D.	N.D.	N.D.	N.D.	N.D.
IV8	104	59.6253	24.7018	D	Sharp	0.31	0.08	2.7	22.1	*(*)
IV9	94	59.5818	24.6782	D		0.80	0.27	3.8	21.0	**
IV10	24	59.4633	24.7873	D		N.D.	N.D.	2.9	N.D.	N.D.
IV11	40	59.5053	24.7655	D		0.31	0.15	2.2	28.7	*
IV12	66	59.5618	24.7167	D		0.31	0.07	5.5	6.9	*(*)

Table 1*b*

*Properties of stations. ST = station, B = bottom depth (m), LAT(N) = latitude (degrees, north), LON(E) = longitude (degrees, east), NAV = navigation system used (D = DGPS with KKJ co-ordinates, G = GPS with WGS-84 co-ordinates, R = Russian co-ordinates), W = peak broadness, v = accumulation rate (cm a^{-1}). S = dry-matter accumulation rate (g cm^{-2} a^{-1}), TC = total carbon in 0-1 cm layer (%), dw% = 0-1 cm dry-weight content (%), flag = suitability of station for chronological monitoring (# = questionable, * = useful, ** = good, *** = very good). N.D. = no data.*

ST		LAT (N)	LON (E)	NAV	W	v'	S	TC	dw %	flag
V1 (GF1)	84	59.7048	24.6853	D		0.49	0.11	N.D.	14.0	**
V2 (GF2)	84	59.8383	25.8598	D		0.28	0.05	N.D.	14.5	*
V3 (GF3)	67	59.7868	27.1232	D	Wide	0.49	0.09	N.D.	6.9	**
V4 (GF4)	35	59.5428	27.7682	D	Wide	0.64	0.27	N.D.	20.8	*(*)
V5 (GF6)	44	60.3382	28.0048	D	Wide	1.33	0.21	N.D.	8.4	*
V6	30	60.0583	29.2000	D		0.72	0.19	N.D.	3.2	**
V7	35	60.2083	28.7667	D		0.72	0.21	N.D.	6.7	**
V8	72	59.9507	27.0110	G		0.48	N.D.	N.D.	N.D.	N.D.
V9	62	59.8673	27.3065	G		0.48	N.D.	N.D.	N.D.	N.D.
V10	65	60.0578	27.1827	G		0.48	N.D.	N.D.	N.D.	N.D.
V12	48	59.9038	27.6252	G		0.21	N.D.	N.D.	N.D.	N.D.
V13	39	60.1172	28.5825	G		0.21	N.D.	N.D.	N.D.	N.D.
V14	36	60.1793	28.7505	G		0.34	N.D.	N.D.	N.D.	N.D.
V15	31	60.0823	29.1500	G		0.62	N.D.	N.D.	N.D.	N.D.
V16	36	60.0743	28.8972	G		0.34	N.D.	N.D.	N.D.	N.D.
V17 (LL3a)	66	60.0667	26.3500	D		1.36	0.20	N.D.	8.3	**
V18 (F40)	37	60.1083	28.8000	D	Wide	0.73	0.19	N.D.	12.5	*
V19 (F41a)	54	60.1030	28.0640	D		0.48	N.D.	N.D.	N.D.	N.D.
V20 (F41b)	51	60.1167	28.0655	D	Wide	0.72	0.14	N.D.	11.4	*
V21 (F42)	61	60.0683	27.4850	G		0.34	N.D.	N.D.	N.D.	N.D.
V22 (LL7)	75	59.8483	24.8317	D		0.33	N.D.	N.D.	N.D.	**
V23	26	60.0380	29.4010	G		0.93	N.D.	N.D.	N.D.	**(*)
V24	31	60.0795	29.3047	G	Wide	0.60	N.D.	N.D.	N.D.	*
V25	38	60.0800	28.9055	G		0.05	N.D.	N.D.	N.D.	#
V26	36	60.0222	28.5827	G		0.05	N.D.	N.D.	N.D.	#
V27	30	59.8993	28.6182	G	Sharp	0.27	N.D.	N.D.	N.D.	*(*)
V28	24	59.7618	28.2428	G		0.38	N.D.	N.D.	N.D.	**(*)
V29	38	59.9192	28.1402	G		0.71	N.D.	N.D.	N.D.	**(*)
V30	60	60.0545	27.6722	G		0.60	N.D.	N.D.	N.D.	*(*)
V31	52	60.1163	28.0677	G		0.38	N.D.	N.D.	N.D.	*(*)
V32	44	60.2610	27.9758	G		0.82	N.D.	N.D.	N.D.	*(*)
V33	45	60.3397	28.0012	G		0.82	N.D.	N.D.	N.D.	*
V34	43	60.3610	27.9063	G	Sharp	0.27	N.D.	N.D.	N.D.	*
V35	70	60.0583	27.1717	G		0.49	N.D.	N.D.	N.D.	**
V36	70	59.9462	27.0148	G		0.16	N.D.	N.D.	N.D.	*
V37	69	59.7878	27.1203	G		0.38	N.D.	N.D.	N.D.	*(*)
V38	56	59.7680	27.3843	G	Sharp	0.16	N.D.	N.D.	N.D.	*
V39	61	60.0690	27.4855	G		0.49	N.D.	N.D.	N.D.	**
V40	59	59.7310	27.1098	G		0.05	N.D.	N.D.	N.D.	#
V41	73	59.8223	27.1203	G		0.27	N.D.	N.D.	N.D.	*(*)
V42	78	59.8558	27.1090	G		0.92	N.D.	N.D.	N.D.	**
V43	73	59.8938	27.1192	G	Wide	0.82	N.D.	N.D.	N.D.	*
V44	69	59.9493	27.1212	G		0.05	N.D.	N.D.	N.D.	#
V45	68	60.0445	27.1238	G	Sharp	0.27	N.D.	N.D.	N.D.	*(*)
V46	68	60.0782	27.1193	G		0.38	N.D.	N.D.	N.D.	*(*)

maximum, the point where highest slope occurred was used in calculations. For examples of maximum layer detection and peak shapes refer to Figure 2.

The ^{137}Cs activity in the profiles was normalized to wet-weight, because more data were available and dw-normalized curves were practically identical with the ww-normalized curves. Peak activity was always found at the same depth, regardless of normalization. Constant deposition of dry matter was assumed. The specific activity in Bq g^{-1} ww (wet-weight) was plotted against depth and

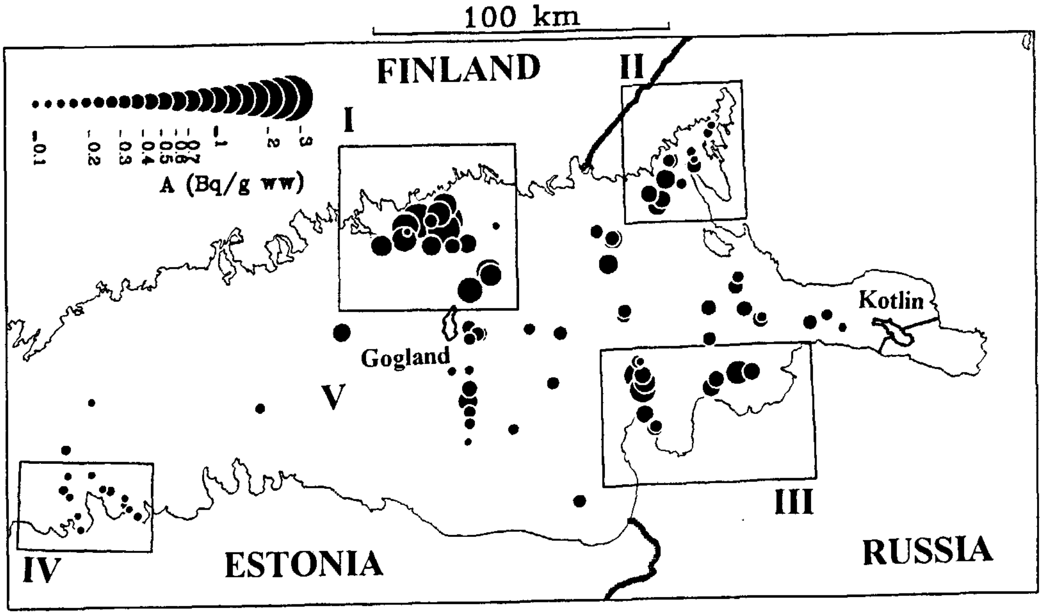

Figure 3

Maximum ^{137}Cs *activity (Bq* g^{-1} *ww) in cores from the five areas of the Gulf of Finland. I = Kotka area, II = Vyborg Bay, III = Luzhskaya – Koporskaya Bights, IV = Tallinn – Ihasalu Bays, V = open-sea stations.*

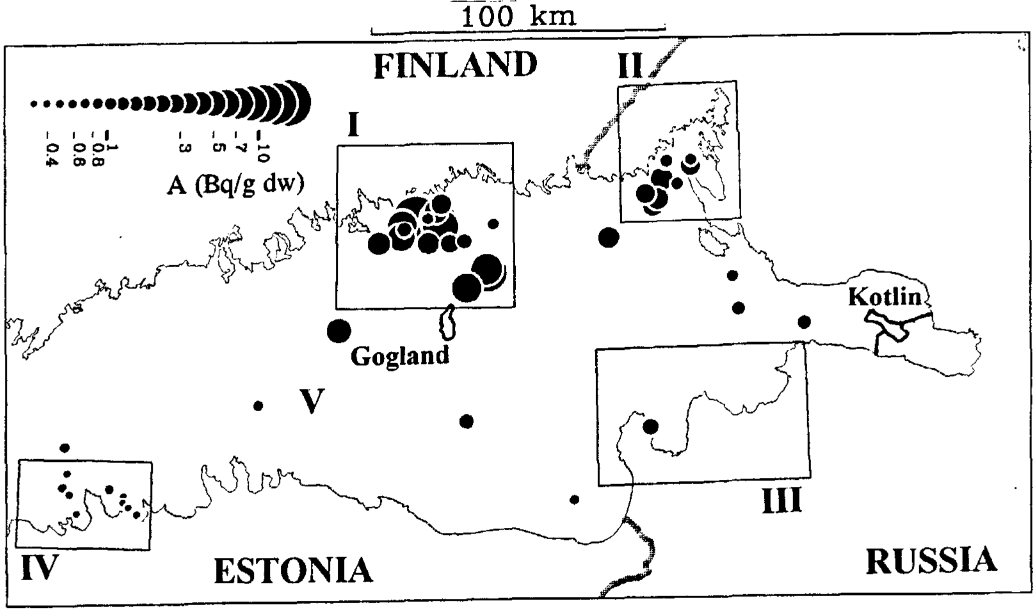

Figure 4

Maximum ^{137}Cs *activity (Bq* g^{-1} *dw) in cores from the five areas of the Gulf of Finland. I = Kotka area, II = Vyborg Bay, III = Luzhskaya – Koporskaya Bights, IV = Tallinn – Ihasalu Bays, V = open-sea stations.*

a spline curve was drawn through the observation points. Average linear accumulation rates were calculated as:

$$v' = z/t \quad (2)$$

where v' is average, linear accumulation rate (cm a^{-1}) (hereafter referred to as accumulation rate), z is depth of caesium maximum (cm) and t is time (a) between sampling and 1 May 1986. As compaction is not considered, the v' values express the average rate for the entire post-Chernobyl layer. Dry matter accumulation rates were calculated based on total dry-mass accumulation over and including the maximum activity layer and core area:

$$S = M/(A_c t) \quad (3)$$

where S = average, dry-matter accumulation rate (g cm^{-2} a^{-1}) (hereafter referred to as dry-matter accumulation rate), A_c = sectional area of the corer (cm^2), M = cumulative dry-mass over and including the maximum activity layer (g) and t = time between sampling and 1 May 1986 (a).

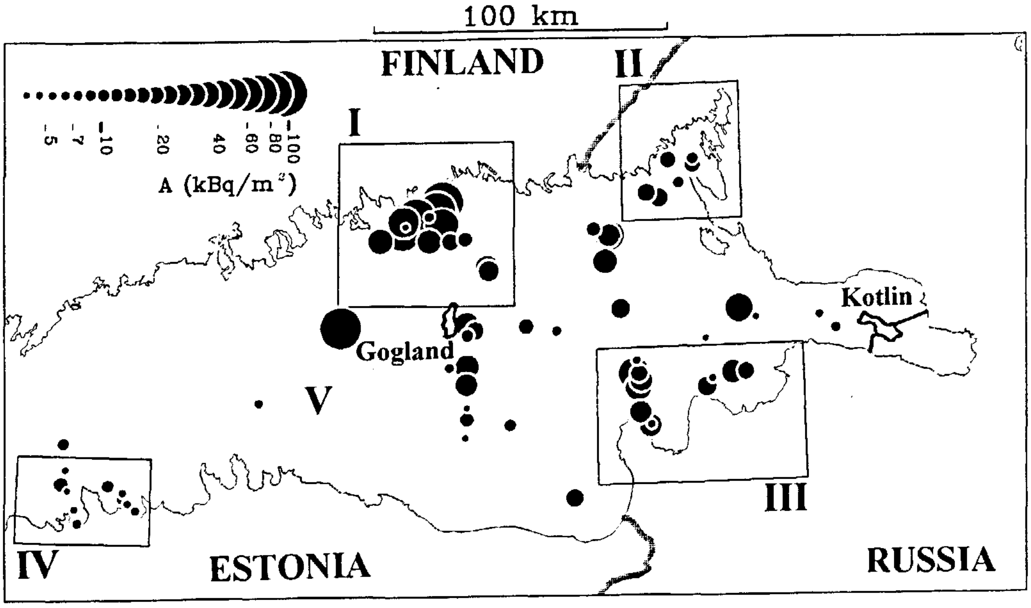

Figure 5

Total ^{137}Cs inventories (kBq m^{-2}) in the five areas of the Gulf of Finland. I = Kotka area, II = Vyborg Bay, III = Luzhskaya – Koporskaya Bights, IV = Tallinn – Ihasalu Bays, V = open-sea stations.

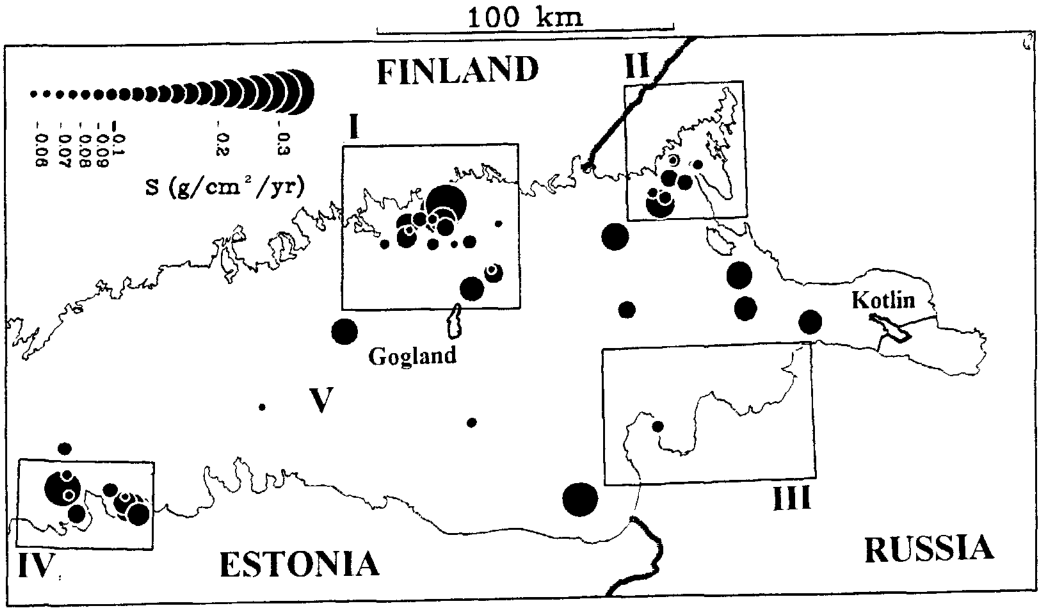

Figure 6

Dry-matter accumulation rates (g cm^{-2} a^{-1}) from the five areas of the Gulf of Finland. I = Kotka area, II = Vyborg Bay, III=Luzhskaya – Koporskaya Bights, IV = Tallinn - Ihasalu Bays, V = open-sea stations.

The main criterion for determining the suitability of sediments for chronological monitoring at any particular station was based on low surficial dry-weight percentage (below 15 %) and high surficial TC concentration (over 4 %; Håkanson, 1986). Additional criteria were high accumulation rate and an apparently low mixing intensity, both deduced from the ^{137}Cs profiles (categorized in Tables 1*a*, *b*). As a result of estimates based on the above criteria, the stations sampled were divided into four illustrative categories (Tables 1*a*, *b*).

RESULTS AND DISCUSSION

In many instances, caesium distribution has been used to confirm results obtained using ^{210}Pb (*e.g.* Robbins *et al.*, 1979; Pempkowiak, 1991; Pourchet and Pinglot, 1989; Sugai, 1990; Tadjiki and Erten, 1994). According to these independent studies, accumulation rates calculated by both methods agree well, but, in cases where effective vertical mixing and relatively high rates are present, the ^{137}Cs method has given more reliable results (*e.g.*

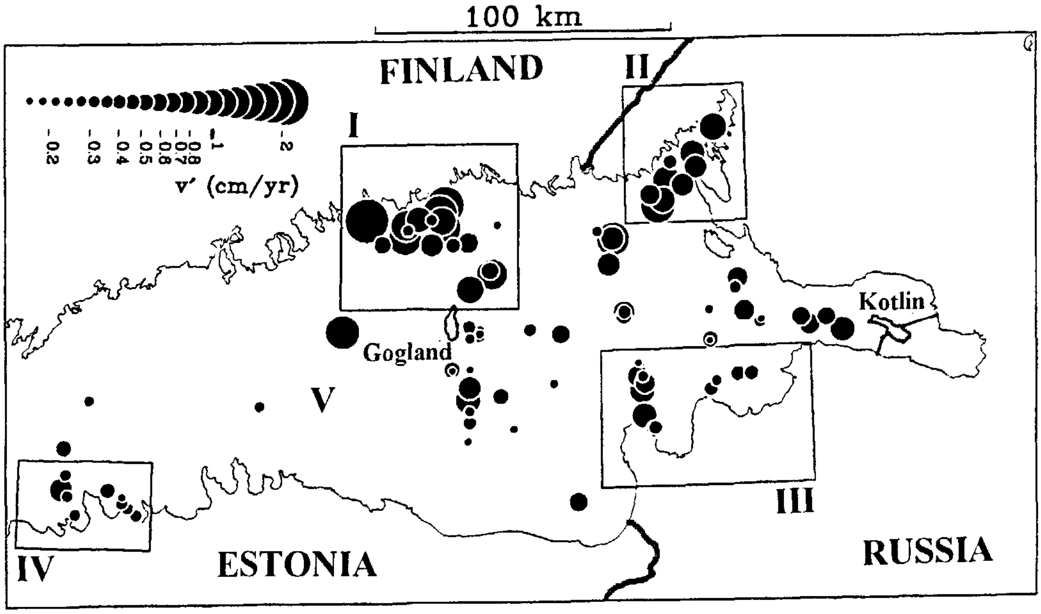

Figure 7

Average accumulation rates (cm a^{-1}) from the five areas of the Gulf of Finland. I = Kotka area, II = Vyborg Bay, III = Luzhskaya – Koporskaya Bights, IV = Tallinn – Ihasalu Bays, V = open-sea stations.

Dominik *et al.*, 1981 ; Zuo *et al.*, 1991 ; Sanchez *et al.*, 1992), although mixing also affects the ^{137}Cs method. The reliability of the accumulation rate and dry-matter accumulation rate values obtained is dependent on firm sorption of ^{137}Cs to the fine particle fraction (under 63 μm) (Aston and Rae, 1982; Desai *et al.*, 1989). In fact, the ^{137}Cs maximum has been reported to be immobile in spite of a downward diffusion of some of the ^{137}Cs (Kyzyurov *et al.*, 1994; Crusius and Anderson, 1995). According to mobility studies in lacustrine sediments, ^{137}Cs appears to be present in two distinct forms, 67-82 % as an immobile form ($K_d > 3 \times 10^5$) and 18-33 % as a reversibly adsorbable form ($K_d \approx 5\ 000$) (Crusius and Anderson, 1995). Unfortunately such data does not exist for the marine environment. The binding is attributed mainly to strong inter-action with clay minerals, especially illite (*e.g.* Cremers *et al.*, 1988; Petersen *et al.*, 1990; Hilton *et al.*, 1994), and, to some extent, to the organic material (Kuijpers *et al.*, 1993). The results of Hilton *et al.* (1992) suggest that Chernobyl radiocaesium was more mobile than the fallout from atmospheric nuclear weapons testing. In cases where sediments have a high porosity and a low clay content, ^{137}Cs chronologies are questionable (Anderson *et al.*, 1987; Crusius and Anderson, 1995).

It has been suggested that the downward migration of ^{137}Cs in sediments is one reason for erroneous ^{137}Cs dating results (Sholkovitz *et al.* 1983; Anderson *et al.*, 1987) and may partly explain the spreading of the peaks. The work of Davis *et al.* (1984) indicates that ^{137}Cs moves easily downwards in lakes with high organic matter and low clay mineral content, probably because of molecular diffusion and adsorption. In the Gulf of Finland, vertical ^{137}Cs distribution cannot be explained only by downward migration, because the peaks spread mostly in an upward direction. This is probably caused by mechanical processes such as bioturbation (Fig. 3). Even if there is some downward migration of ^{137}Cs, the immobility of the maximum layer (Ritchie *et al.*, 1973 ; Robbins and Edgington, 1975; Livingston and Bowen, 1979; Crusius and Anderson, 1995) seems to be the dominant characteristic of the ^{137}Cs in the sediments, providing further evidence of the reliability of ^{137}Cs as a time marker.

High ammonium concentrations can cause the desorption of ^{137}Cs from sediments (Comans *et al.*, 1989), but in the bottom waters of the Gulf of Finland during the past 5-10 years, nitrogen has been present predominantly in the form of nitrate (Perttilä *et al.*, 1995) and desorption of ^{137}Cs is assumed to be negligible.

In most of the cores studied, the topmost part was recent clayey mud. In some cores tunnels and holes were observed, probably caused by benthic animals. Industrial fibres were seen frequently in cores from the Kotka area. Colonies of white Beggiatoa bacteria were seen in a few cores. In general, sediments from the Estonian side and also from some stations east of Gogland seemed to have a higher clay content than samples on average, which was reflected in their dry-weight percentages (Tables 1*a*, *b*).

Spatial activity distribution

Three spatial activity distributions were obtained, from dw-normalized values, ww-normalized values and by using the total ^{137}Cs inventory. Because the data on dw- normalized values are scarce and the dw- and ww- normalized activities correlated sufficiently ($r^2 = 0.76$), the discussion will focus on the total inventories and distributions based on wet-weight. When looking at the maximum ^{137}Cs concentration in cores (Fig. 3; Tables 1*a*, *b*), the highest levels of ^{137}Cs in the sediments are found at shallow stations near Kotka town (area I: 0.06-2.4 Bq g^{-1}, average

0.85 Bq g^{-1}). In Vyborg Bay (area II) and the Luzhskaya and Koporskaya Bights (area III), the activity is medium-high (0.10-0.62 Bq g^{-1}, average 0.33 Bq $g^{-1}$and 0.12-1.0 Bq g^{-1}, average 0.54 Bq g^{-1}, respectively). The lowest activities are found in area IV (0.09-0.17 Bq g^{-1}, average 0.12 Bq g^{-1}). At open-sea stations (area V) the activity is moderate (0.18-0.62, average 0.36 Bq g^{-1}) and in the easternmost Gulf, along the Gogland-Kotlin transect, activities are very uniform (0.35-0.42 Bq g^{-1} between stations V10 and V6). Present surface-layer activity was very low at all stations (0.05-0.20 Bq g^{-1}), with the exception of stations I9 (0.40 Bq g^{-1}), III9 (0.28 Bq g^{-1}) and V26 (0.32 Bq g^{-1}). In the last two cases the surface activity seemed relatively high due to low accumulation rates. Dry-weight based activities were 0.14 - 15.3 Bq g^{-1}, *see* Fig. 4.

The total deposition of ^{137}Cs varies between 1.4 and 80.5 kBq m^{-2} with an average value of 21 kBq m^{-2} (Fig. 5). To a large extent, the overall pattern resembles the ww-normalized distribution, but some of the stations south of Gogland island and in the eastern open sea area received more of ^{137}Cs fall-out than the ww activity picture suggests. The total inventories agree quite well with earlier estimations of 16±10 kBq m^{-2} (Anisimov *et al.*, 1991). The extrapolated average, total ^{137}Cs content for the Gulf of Finland accumulation areas (estimated 25 % of total area), would thus be approximately 160 TBq. Corrected to the 1986 level, this is 190 TBq, which means that roughly 1 % of the Chernobyl-produced ^{137}Cs was deposited in Gulf of Finland recent sediments.

The geographical distribution shows that ^{137}Cs activity increases from west to east, with the highest activities being found along the Kotka- Koporskaya/Luzhskaya transect and in sediments from the outer parts of the Vyborg Bay. Activity decreases and levels off in the Neva Estuary. These results agree well with Chernobyl ^{137}Cs distribution over the landmass around the Gulf of Finland (Arvela *et al.*, 1987; Baltic Marine Environment Protection Commission, 1994) and also with ^{137}Cs distribution in surface water after the accident (Baltic Marine Environment Protection Commission, 1989). The cumulative rainfall pattern in Finland from 27 April to 2 May 1986 shows high precipitation in the northern Gulf of Finland near Kotka (Arvela *et al.*, 1987) and may explain, to a great extent, the spatial distribution, but ^{137}Cs deposition in the Kotka and Luzhskaya areas has been affected by transport from the Kymi and Luga rivers.

Shapes of the ^{137}Cs profiles

Four types of ^{137}Cs profiles can be recognized in our data pool: (i) profiles with a single narrow maximum near the core top or deeper (stations I9 and IV12); (ii) profiles with one strong and one or two less intensive maxima (station I13); (iii) profiles with an intense, broad peak (station V20); and (iv) profiles with a diffuse peak (station III10). Examples of the different types are shown in Figure 2. Tables 1*a*, *b*, with data on all station properties, also list stations with distinctively sharp or wide ^{137}Cs peaks. Distinctive mixing is observed at stations in the Kotka area (I) and at many open-sea stations (area V). In the Luzshkaya Bight (stations III4-III10), mixing is also relatively high. In Vyborg Bay (area II) and the Koporskaya Bight (stations III1-III3), mixing is rather low. The least mixing seems to occur in Estonian area (area IV). Our results suggest that mixing of sediment strata is a common phenomenon in the Gulf of Finland and can be caused by recent bioturbation, physical effects such as water currents (Perttilä and Niemistö, 1993), and sediment redistribution due to episodic, near-bottom currents and movement of porewater.

In the Gulf of Finland, the main cause of bioturbation, vertical mixing of the uppermost sediment and ^{137}Cs band spreading are the amphipods *Monoporeia affinis* and *Saduria entomon* and the mollusc *Macoma balthica*, all of which have been increasing in number since the middle 1980s (Andersin and Sandler, 1991) as a result of improved oxygen conditions in bottom water layers. During the late 1980s *Marenzelleria viridis* appeared for the first time in the Gulf of Finland; this species is capable of mixing sediments to a depth of at least 20 cm (Bick and Burckhardt, 1989; Zettler *et al.*, 1995). Other causes which may explain differences in peak width are lateral transport, material input from catchment areas and sediment re-suspension. Wide peaks are found in the vicinity of the Kymi River (Kotka area), Saimaa Canal (Vyborg Bay) and the Luga River (Luzhskaya Bight). Also, the wide radiocaesium peaks at stations V18 and V20 (Fig. 3) may be caused, in part, by the effects of the Neva River. Furthermore, the data show that band spreading takes place more easily in sediments with low dry-weight percentages. This can be seen by comparing results from area IV (high clay content, low organic material content) with results from other stations. At some stations exhibiting broad peaks, spreading may be extended by the effect of ships, trawling and so on. During the coring and sub-sampling, radiocaesium from the active layers may smear the walls of the core tube and contaminate lower layers. With the corers used (e.g. Niemistö, 1974), the contribution of this effectis is considered negligible by the authors.

The pulse retention time of ^{137}Cs from Chernobyl in the water-mass of the Gulf of Finland has been short. This can be seen from the ^{137}Cs levels in the open waters of the Gulf of Finland, which were elevated in 1986 from approximately 20 Bq m^{-3} to 660 Bq m^{-3} at station LL3a (V17) and by 1993 had fallen to approximately 60 Bq m^{-3} (Baltic Marine Environment Protection Commission, 1994). The activity decline in the water was abrupt in comparison with concentration changes in the Baltic proper, the Bothnian Bay and the Bothnian Sea; and the present ^{137}Cs level in the Gulf of Finland is now the lowest of all the sea areas monitored annually by the Finnish Centre for Radiation and Nuclear Safety. In consequence, one would expect to find narrow, intense ^{137}Cs peaks in the sediments, and this is indeed observed at several stations. However, according to year-by-year sediment monitoring in the Gulf of Finland (stations I15 and V17), deposition of radiocaesium in open sea areas may have taken 1-2 years (Ilus *et al.*, 1987; Ilus *et al.*, 1991; Saxén *et al.* 1989; Ilus *et al.*, 1993). Our calculations were based on a time interval from 1 May 1986 to the day of sampling and, as a consequence of the longer sedimentation time of ^{137}Cs, the accumulation rate and dry-matter accumulation values obtained in this study may be slightly lower than expected.

Dry-matter accumulation rates and accumulation rates

As a result of the differences in dry-matter content, the distribution of the dry-matter accumulation rate (S ; Fig. 6) is rather even, the highest rates being found in area V (0.05-0.27 g cm^{-2} a^{-1}, mean 0.17 g cm^{-2} a^{-1} ±0.06 g cm^{-2} a^{-1}). The values for S are relatively high in area IV (0.08-0.27 g cm^{-2} a^{-1}, mean 0.15 g cm^{-2} a^{-1}), less in area I (0.01-0.30 g cm^{-2} a^{-1}, mean 0.14 g cm^{-2} a^{-1}) and least in area II (0.06-0.22 g cm^{-2} a^{-1}, mean 0.12 g cm^{-2} a^{-1}). For area III, the only result is from station GF5 (0.10 g cm^{-2} a^{-1}). The highest, single dry-matter accumulation rates are found near Kotka (area I), where the flux of particles from the Kymi River is marked. The mean dry-matter accumulation rate for the whole Gulf accumulation area is 0.15 g cm^{-2} a^{-1} ±0.07 g cm^{-2} a^{-1} (standard deviation). Although lateral transport of sediment in open sea areas may occur, open sea basins appear to collect particles slightly more efficiently than those in the more coastal zones.

Spatial distribution of accumulation rates (v'; cm a^{-1}) is illustrated in Figure 7, which shows v' is more variable than S. The distribution of accumulation rate indicates that most of the stations with very high v' are located in area I (0.08-1.94 cm a^{-1}, mean 0.92 cm a^{-1}). In areas II and III, v' varies from high to moderate (0.40-1.36 cm a^{-1}, mean 0.84 cm a^{-1} and 0.07-0.91 cm a^{-1}, mean 0.48 cm a^{-1}, respectively). In the more maritime area IV, the values for v' are low (0.06-0.80 cm a^{-1}, mean 0.35 cm a^{-1}). In general, v' is also low in area V (0.05-1.36 cm a^{-1}, mean 0.50 cm a^{-1} ±0.31 cm a^{-1}) in comparison with the other areas. From Gogland to Kotlin, the values for v' increase from 0.21 (station V10) to 0.73 cm a^{-1}, being highest at stations V20 (0.72 cm a^{-1}), V18 (0.73 cm a^{-1}), V15 (0.62 cm a^{-1}) and V6 (0.72 cm a^{-1}). The highest v' values are found at the shallower sampling stations, with the exception of station IV9 (94 m; 0.80 cm a^{-1}). For the entire Gulf of Finland accumulation area (all samples), the mean accumulation rate is 0.60 cm a^{-1} ±0.39 cm a^{-1}.

The clayey character (high dry-matter content) of stations I4, I7, III4, IV4, IV10 and IV11 is reflected in low v' values, but it should be noted that the values for S in the Tallinn-Ihasalu area are rather high. If the clay content really is a key factor determining the reliability of ^{137}Cs results, downward migration of ^{137}Cs should encounter more hindrance in clayey Gulf of Finland sediments than in loose, organic, lake deposits. Our recent investigations indicate that clay content alone cannot explain changes in ^{137}Cs profiles, *i.e.* the values obtained for v' and S reflect the true accumulation rates.

Using Hg as a tracer, Pitkänen (1994) has found accumulation rates of 0.43-1.0 cm a^{-1} and dry-matter accumulation rates of 0.097-0.14 g cm^{-2} a^{-1} in Ahvenkoski Bay in the Kotka area. The values for S calculated here agree quite well with the results of Pitkänen (1994), but over half of the stations in the Kotka area show much higher v' values. These higher rates are advantageous to sediment studies, because they provide more accurate chronological data.

According to a previous open-sea study (Voipio, 1981), the average accumulation rate for the uppermost 10 cm at station XV1 (I15), eastern Gulf of Finland, has been estimated at 0.74 cm a^{-1}. Voipio's results showed substantially lower accumulation rates in basins in other parts of the Baltic Sea (0.13-0.24 cm a^{-1}). Based on radionuclide balance calculations, an average accumulation rate of 0.4 cm a^{-1} for the whole Gulf of Finland has been reported by Salo *et al.* (1986). The rates observed in this study are noticeably high when compared with these earlier results. This may reflect differences in techniques (the earlier estimates used ^{210}Pb dating); it is also possible that increased erosion and eutrophication have accelerated recent sedimentation. Although no really conclusive results exist regarding the latter, algal blooms in the Gulf of Finland have been intense during the past few years. The eastern part of the Gulf of Finland is considered to be an important sedimentation area (Pitkänen, 1991) because of particle flux from the Neva River. Our results indicate that accumulation rates in the eastern Gulf are somewhat lower than the average for the whole Gulf of Finland, and far from the extremely high accumulation rates found in the Kotka and Luzhskaya areas, where particle input from rivers may increase the accumulation rates. However, due to the large area of the eastern Gulf basins, the contribution of these basins to the overall sedimentation is still of the greatest importance. Our study area included sedimentation basins in Russian territorial waters where, until recently, research was prohibited. Accumulation rates in some of these Russian basins appears to be extremely high.

Our data comprise the results of analyses of samples taken from accumulation basins with active sedimentation. In calculating a mean accumulation rate value for the whole Gulf of Finland, these data can only be considered to represent approximately 1/4 of the Gulf's area, the other 3/4 being either non-deposition areas or bottoms with active erosion. The very high rate of sedimentation measured in the Kotka area increases the average accumulation rate of 0.60 ± 0.39 cm a^{-1} for the entire accumulation area. However, if the areal share of accumulation bottoms is taken into account, the average rate of sedimentation for the whole Gulf of Finland (29 600 km^2) appears to be 0.15±0.10 cm a^{-1}. This result accords quite well with the 0.4 cm a^{-1} approximation presented by Salo *et al.* (1986) and the 0.16 cm a^{-1} presented by Perttilä *et al.* (1995). For dry-matter accumulation rate, the corresponding average value is 0.04±0.02 g cm^{-2} a^{-1}, but comparisons using mass accumulation rates cannot be made since there are no previous data.

It is important to bear in mind that the accumulation rates reported here are only applicable to the exact position of locations sampled. Due to the profuse patchiness of Gulf of Finland sediments a deviation of 100 or even 10 m could reveal different accumulation rates and radiocaesium levels. Measurements for each and every station can only suggest what the rates might be beyond the station. Variation of the deposition rate within basins is a subject that should be given more attention. Erosion caused by bottom currents disturbing the surficial sediment layer has been recorded on underwater videofilm as a rolling-off of the surficial layer, like the rolling-up of miniature carpets (Perttilä and Niemistö, 1993). The overall extent of the above phenomena is not known. Bioturbation has been discussed earlier.

The classification of the stations in this study, according to peak width, surficial dry-weight content, accumulation rate and TOC content, gives an indication of their suitability for both chronological studies and monitoring purposes. According to our results, stations I17, III4, IV1, V25, V26, V40 and V44 are not good as monitoring stations and the suitability of a number of other stations (marked with an *) should be reconsidered. On the other hand, many new stations with seemingly good applicability were discovered (Tables 1*a*, *b*).

CONCLUSIONS

Data about accumulation rates, dry-matter accumulation rates and radiocaesium activity in the Gulf of Finland are presented. Results indicate that the ^{137}Cs technique is suitable for estimating accumulation rates and dry-matter accumulation rates in the Gulf of Finland, especially to the east of the Helsinki-Tallinn transect, because: (i) accumulation rates and dry- matter accumulation rates are high; (ii) radiocaesium activity is high (large inventories); (iii) radiocaesium stratification remains well defined despite considerable mixing; and (iv) it is probable that the high clay (illite) content in Gulf of Finland sediments enhances the binding of ^{137}Cs to sediments.

Further studies are needed in order to evaluate more accurately the micro-scale effects of clay content variations and the effects of benthic animals on ^{137}Cs profiles. By classifying stations according to their monitoring-suitability, sites for long-term pollution monitoring can be selected. Some of the previously monitored stations should be reconsidered, especially where mixing is observed to be intensive. In bottom sediments, the spatial distribution of radiocaesium peak activity and total inventory was found to correspond with distribution and activity patterns in the soils of the surrounding landmass and in sea water, and this is, in part, a result of the meteorological conditions prevailing at the time of the Chernobyl fallout. Large variations in accumulation rates and dry-matter accumulation rates throughout the Gulf of Finland reflect the patchy character of seafloor and the effect of the riverine input. Our results show that there are very active local sedimentation basins in coastal areas, but that - in the long run - these basins are probably only temporary storages. The deeper basins in the central and eastern Gulf of Finland are functioning as the more permanent sinks, as dry-matter accumulation rates indicate most clearly.

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