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Transfer of Chernobyl-derived ^{137}Cs into fishes in some Finnish lakes

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ABSTRACT

This report summarizes STUK's work for the hydrological modeling (WG 4) in RODOS C, a project co-ordinated by the EU, in 1996-1999.

The role of STUK in the project was to provide a data set on the radio-caesium contents in different types of fish and lakes in northern European environmental conditions for the development of a dynamic regional model describing radio-caesium transfer into fish. The co-operating institute, Technical Research Centre of Finland (VTT), was responsible for the modelling work in this project. Besides the analysed data on ^{137}Cs in the various fish species in the lakes, background information was produced on lakes and their drainage areas that might affect radio-caesium transfer into fish , which was needed for the development of fish, lake and drainage basin models. The role of STUK included also providing another, independent data set for the validation of the model. The proposals and needs of the co-operating institute, VTT, were taken into account (Suolanen 1998).

One of the factors strongly affecting the transfer of ^{137}Cs into fish is the nutrition level of the lake. The average transfer of ^{137}Cs in predators at the time of maximum activity concentrations in oligotrophic lakes was found to be up to 0.10 m^2/kg, implying that approximately 10% of the amount of ^{137}Cs deposited on one square metre is transferred into 1 kg of fish. The corresponding transfer in eutrophic lakes was clearly lower, i.e. 3-4%, at the time of maximum concentrations, which usually occurred 1-3 years after the deposition, depending on the fish species. These time-dependent transfer coefficients can be regarded as a kind of a lake-specific model. If deposition to the lake is known, the activity concentrations

in fish can be estimated within specific uncertainty limits, by multiplying the deposition value by the transfer coefficient at a certain time point. Temporal changes in annual averages of transfer coefficients with variation for a certain set of lakes and for three lake types, oligotrophic, eutrophic and mesotrophic, are given here.

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Avainsanat Cesium 137, järvikalat, kulkeutuminen, ravinteet

TIIVISTELMÄ

Tähän raporttiin on koottu aineisto, jolla STUK osallistui EU:n koordinoimaan onnettomuusvalmiutta palvelevaan projektiin RODOS C, sen hydrologista mallintamista koskevaan osaan WG 4 vuosina 1996–1999.

STUK:n tehtävä oli antaa edustava aineisto Suomen ja samalla Pohjois-Euroopan olosuhteisiin kehitettävän dynaamisen kulkeutumismallin kehittämistä varten erityyppisten järvien kalojen ^{137}Cs-pitoisuuksien ajallisista muutoksista. Kalojen ^{137}Cs-pitoisuuksien ajallisten muutosten lisäksi hankittiin mallintajan tarvitsemia tietoja järvistä ja niiden valuma-alueista. Mallin kehittämisen jälkeen STUK toimitti edellisestä riippumattoman aineiston mallin validointia varten. Alueellisen mallin kehittämisestä tässä projektissa vastasi Valtion teknillinen tutkimuskeskus, VTT, jonka toivomukset ja tarpeet taustatietoja hankittaessa otettiin huomioon.

Eräs tärkeimmistä tekijöistä, jotka vaikuttavat ^{137}Cs:n kulkeutumiseen laskeumasta kaloihin, on järven ravinnetaso. Niukkaravinteisissa järvissä ^{137}Cs:n kulkeutuminen petokaloihin ajankohtana, jolloin kalojen pitoisuudet olivat korkeimmillaan, oli keskimäärin jopa 0,10 m^2/kg, mikä tarkoittaa, että 10 % yhdelle neliömetrille laskeutuneesta radioaktiivisesta cesiumista siirtyi yhteen kilogrammaan kalaa. Vastaava kulkeutuminen runsasravinteisissa järvissä oli vähäisempää, siellä vain keskimäärin 3-4 % neliölle tulleesta ^{137}Cs:stä siirtyi yhteen kiloon petokalaa. Raportissa annetaan järvikohtaiset keskimääräiset siirtokertoimet vaihteluväleineen eri vuosina onnettomuuden jälkeen sekä vastaavat kertoimet niukkaravinteisille, runsasravinteisille ja niiden välimuotoa oleville järville. Näitä siirtokertoimia käyttäen voidaan laskeumatilanteessa arvioida laskeumatietojen perusteella kalojen ^{137}Cs-pitoisuuksien suuruusluokkia.

CONTENTS

page

1 INTRODUCTION

The role of STUK in the development and validation of the hydrological model for environmental conditions of northern Europe in RODOS C, a project co-ordinated by the EU, was to provide data on the radiocaesium contents in different fish types in different types of lake. Besides the analysed data on ^{137}Cs in the various fish species in the lakes, background information was produced on lakes and their drainage areas that might affect radiocaesium transfer into fishes and that was needed for the development of fish, lake and drainage basin models. Another, independent data set for validation of the developed model was provided by STUK. The proposals of the co-operating institute, Technical Research Centre of Finland (VTT), responsible for the models, concerning data on lakes and their catchments were taken into account (Suolanen 1998). This report summarizes the work done at STUK for the hydrological modelling WG 4 in RODOS C in 1996-1999.

2 GENERAL INFORMATION ON THE LAKES IN FINLAND

The percentage of lakes and rivers is high in the Nordic countries. In Finland, for example, lakes and rivers cover about 10% of the total area, and in some areas the lake coverage is as high as 25%. The lakes tend to be rich in humic substances, deficient in nutrients, phosphorus in particular, and slightly acidic. Due to the high contents of humic substances and iron in the water, sight depth is only a few metres.

The lakes are generally shallow, their mean depth being about 7 m. The large lakes have several basins, many islands and a very long shoreline. Finnish water systems can be divided into three groups based on the runoff situation:

- inland watercourses, where numerous large lakes level off the annual water discharge variations;
- river watercourses in coastal areas, where temporal changes in water discharge are marked; and
- water systems of northern Finland, where water discharge is relatively high throughout the year, but there are fewer lakes in the river catchments.

The annual variation in lake water temperature is considerable, for example 12 ^{o}C at a depth of 20 m in a large lake in central Finland. The lakes in the interior usually begin to freeze in early November. The break-up time of the ice varies less than the freezing time, and is not so dependent on the area or depth of the lake. Shallow lakes may freeze to the bottom in the course of the winter, but usually 40-70% of the water mass is frozen. The lakes are dimictic and directly stratified in summer and inversely stratified in winter. Marked seasonal changes in the water stage are typical. In natural lakes the water stage reaches its maximum value during the spring flood and its minimum value in either late winter or late summer.

The main factors in water circulation - precipitation, evaporation and runoff - vary from one part of the country to the other. Precipitation is highest in southern Finland, about 750 mm/yr and lowest in northern Finland, about 500 mm/yr; the mean annual precipitation is 650 mm/yr. Precipitation to lakes is somewhat lower than to the soil. Evaporation decreases from south to north, being 300-400 mm/yr in the south and 100-300 mm/yr in the north. About 50 mm more is evaporated from lakes than from the soil. Runoff is affected by the type of drainage area: the larger the drainage area, the longer the gathering time of runoff and the gentler the runoff peaks. Runoff is lowest in the lake area of southern Finland: 5-7 $l/(s*km^2)$ and highest in the northeast, 12-13 $l/(s*km^2)$, which is the wettest part of Finland (most snow, low evaporation). The average runoff in Finland is about 300 mm/yr.

3 LAKES SELECTED FOR MODEL DEVELOPMENT

STUK has produced a fairly large volume of data on radiocaesium in freshwater fish since the Chernobyl accident. From these data the following six lakes were selected for model development: Alinenjärvi, Kallavesi, Kyrösjärvi, Nilakka, Iso Valkjärvi and Pyhäjärvi (Pirkkala). The average deposition of ^{137}Cs in the lake catchments ranged from 12 to 55 kBq m^{-2} in 1986. All the lakes are located in southern and central Finland (Fig. 1.).

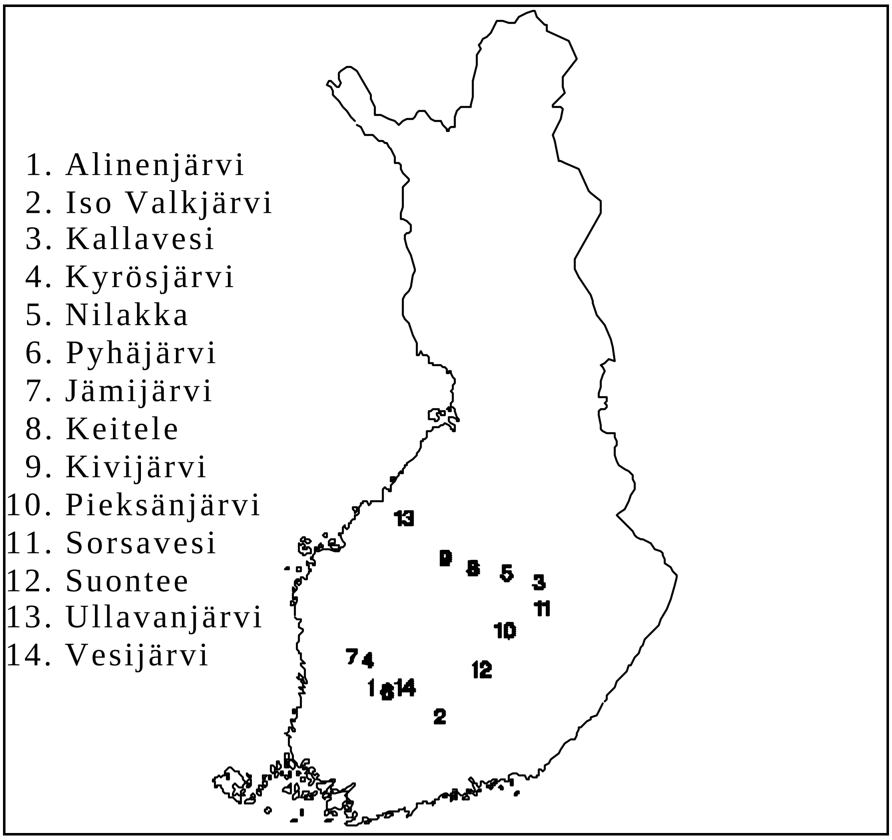


Figure 1. *Location of lakes selected for model development (lakes 1-6) and validation (lakes 7-14).*

The *lake model* includes some characteristics of the lakes. Data on surface area and depth form the basis for describing the dilution of the radionuclides deposited. In size, the lakes vary from 0.042 to about 900 km^2 and in mean depth from 2.8 to 10.6 m. Water residence time is informative about radionuclide removal with water flowing from the lake or about the retention of radionuclides in the lake. The theoretical water residence times of the lakes were from 61 to 1095 days (Table I). Water chemical parameters vary considerably, for instance, pH from 5.6 to 7, and the electrical conductivity of surface water from 1.5 to about 10. The concentration of K, colour, sight depth, and concentrations of oxygen, total phosphorus, total nitrogen and chlorophyll a at different depths and including seasonal variations are also given (Tables II and III). The lakes selected differ in trophic status, which is known to be one of the key factors in the transfer of ^{137}Cs into fish. The parameters that best describe the trophic status of the lake are total phosphorus and chlorophyll a. One of the lakes selected for model development is oligotrophic, three are mesotrophic and two are eutrophic. The amount of plankton in the lake can be described by the chlorophyll a content. Another important factor is electrical conductivity, which usually correlates with the potassium content in the water (Tables II and III).

The *drainage basin model* includes information on the size and land use of the lake catchments expressed as percentages of forests, fields and pasture, peatlands and water (Tables IV and V). The catchments differ a great deal from each other not only in surface areas but also in land use, thus affecting runoff from the catchment to the lake. The maps show the topography in the immediate surroundings of the lakes. Data on the erosion rate of suspended solids from drainage basins to lakes, which is considered by the modeller to be of importance for radionuclide transfer, was not however, available. Neither the sedimentation rate of the suspended solids to the lake bottom nor the resuspension rate of the suspended solids from the bottom is easy to quantify. The data on lakes and their catchments and water chemical parameters were taken from references (Alueellinen tilaraportti 1-5, Atlas of Finland Folios 123-126, 234, Ekholm 1993, Kuusisto 1992, Maa- ja metsätalous 1994, Maanmittaus 1995, Maatalouslaskenta 1990, Metsätilastollinen vuosikirja 1994-95, Publications of the National Board of Waters 32, 34, 36, 38, 42, Raatikainen, Kuusisto 1990, Vesihallituksen julkaisuja 20, Vesi- ja ympäristöhallinnon julkaisuja 20, Ympäristötilasto 1994, Kähäri et al. 1987) or extracted from the water quality register of the Finnish Environment Agency's environmental data system.

Table I. Morphological data and theoretical water residence time (d) of the lakes selected for model development.

Lake	Drainage basin code	Municipality of the lake outlet	Coordinates of the lake outlet	Surface area (km^2)	Volume (10^6 m^3)	Mean depth (m)	Max. depth (m)	Theor. residence time (d)
Alinenjärvi	35.212	Nokia	61 30N 23 28E	0.45	1.24	2.8		183
Iso Valkjärvi	35.787	Lammi		0.042	0.13	3.0	8	1095
Kallavesi	4.27	Leppävirta (bif.)	Konnus: 62 33N 27 45E Karvio: 62 31N 28 38E	898	7990	8.9	90	547
Kyrösjärvi	35.521	Hämeenkyrö	61 40N 23 12E	96.2	1020	10.6	48	437
Nilakka	14.731	Tervo	63 01N 26 40E	167.9	755	4.5	18	416
Pyhäjärvi	35.211	Nokia	61 28N 23 32E	124	770	6.2	46	61

Table II. *Water chemical data (pH, electrical conductivity, K, and colour) and sight depth of lakes at different depths, 1m means one metre below the surface, 2h-1m one metre above the bottom and 2h the average in the whole water column. Values for water chemical parameters refer to the end of the two stratification periods, for smaller lakes annual values are given.*

Lake	**pH**			**Electrical conductivity (mS/m)**			**K (mg/l)**	**Colour number (mg Pt/l)**			**Sight depth (m)**
	1m	**2h-1m**	**2h**	**1m**	**2h-1m**	**2h**		**1m**	**2h-1m**	**2h**	
Alinenjärvi											
Mean			6.1			5.8	0.6			67	
Iso Valkjärvi											
Mean	5.6			1.5			0.4	68			2.0
Kallavesi											
March	6.7	6.6	6.6	4.9	6.7	5.5	1.7	64	69	63	3.5
August	7.1	6.5	6.7	5.0	5.2	5.1		52	60	55	3.3
Mean	6.9	6.5	6.7	5.0	6.0	5.3	1.7	58	65	59	3.4
Kyrösjärvi											
March	6.2	6.4	6.3	4.7	6.8	5.4	1.4	134	131	127	1.8
August	6.7	6.0	6.4	4.5	4.9	4.7		80	93	90	1.9
Mean	6.5	6.2	6.4	4.6	5.9	5.1	1.4	107	110	108	1.9
Nilakka											
March	6.7	6.2	6.4	4.5	5.2	4.7		41	133	86	3.8
August	7.0	7.0	7.0	4.3	4.3	4.3		45	46	45	3.1
Mean	6.9	6.6	6.7	4.4	4.8	4.5		43	90	66	3.5
Pyhäjärvi											
March	6.6	6.4	6.6	10.4	12.2	11.2	2.1	49	73	55	2.4
August	7.1	6.7	7.0	9.2	10.1	9.4		45	104	61	1.8
Mean	6.8	6.6	6.8	9.8	11.2	10.3	2.1	47	89	58	2.1

Table III. *Seasonal variations in water chemical data (oxygen and saturation % of oxygen, total P and total N, and chlorophyll a) at different depths, 1m means one metre below the surface, 2h-1m one metre above the bottom and 2h the average in the whole water column.*

Lake	**Oxygen (mg/l)**			**Oxygen saturation (%)**			**Tot.P (µg/l)**			**Tot.N (µg/l)**			**Chlo-rophyll a (µg/l)**
	1m	**2h–1m**	**2h**	**1m**	**2h-1m**	**2h**	**1m**	**2h-1m**	**2h**	**1m**	**2h-1m**	**2h**	**0-2m**
Alinenjärvi													
Mean			7.6			67			11			367	3.1
Iso Valkjärvi													
Mean							23			512			
Kallavesi													
March	12.0	3.9	9.2	83	28	66	18	40	23	618	724	649	
August	8.5	7.0	7.5	87	59	68	16	20	17	535	676	566	
Mean	10.3	5.5	8.4	85	44	68	17	30	20	577	675	607	7.8
Kyrösjärvi													
March	12.0	1.6	9.1	83	12	64	29	57	36	779	849	801	
August	8.7	5.4	6.1	89	47	66	22	36	26	746	713	773	
Mean	10.4	3.5	7.6	86	30	65	26	47	31	763	781	787	13.7
Nilakka													
March	13.5	5.7	9.2	94	42	66	10	30	19	473	620	526	
August	8.7	8.5	8.6	88	86	87	12	13	12	356	364	356	
Mean	11.1	7.1	8.9	91	64	77	11	22	16	415	492	441	7.0
Pyhäjärvi													
March	10.5	4.7	8.8	74	31	62	21	55	31	822	1438	1048	
August	8.6	3.0	6.2	89	30	69	28	122	49	710	1092	814	
Mean	9.6	3.9	7.5	82	31	66	25	88	40	767	1265	932	10.4

Table IV. *Data on catchments of the lakes.*

Lake	Drainage area (km^2)	Codes of the sub-areas	Code of the nearby catchment	Area of the nearby catchment (km^2)
Alinenjärvi	9.7			2.3
Iso Valkjärvi	0.17			
Kallavesi	16302	4.272 - 4.273	4.272	3219
		4.275 - 4.276	4.273	
		4.278	4.281	
		4.28	4.282	
		4.5 - 4.7	4.611	
Kyrösjärvi	2627	35.52 - 35.58	35.521	358
Nilakka	2157	14.73 - 14.75	14.731	467
Pyhäjärvi	17073	35.2 - 35.4	35.211	442
		35.6 - 35.8		

Table V. *Land use in the drainage basins and nearby catchments of the lakes in percentages of total area. For smaller lakes (Alinenjärvi and Iso Valkjärvi) the nearby catchments were included in the total drainage area.*

Lake	Water (%)	Cultivated area (%)	Open land (%)	Open peat-lands and peat production area (%)	Coniferous dominated peatland (%)	Forest (%)	Built-up area (%)
Alinenjärvi							
Drainage basin	4.1	0.9	28.2	0.2	4.6	50.0	11.8
Iso Valkjärvi							
Drainage basin	4.1	3.1	18.0	0.2	9.1	65.2	0.2
Kallavesi							
Drainage basin	14.3	7.7	20.1	0.9	14.4	42.0	0.5
Nearby catchment	30.1	8.0	13.0	0.2	2.9	44.7	1.2
Kyrösjärvi							
Drainage basin	8.2	9.6	22.3	2.7	11.0	45.6	0.5
Nearby catchment	25.6	18.2	15.8	0.1	1.6	37.4	1.4
Nilakka							
Drainage basin	17.1	3.8	10.3	1.3	13.3	54.0	0.3
Nearby catchment	36.0	3.0	8.7	0.4	6.8	44.8	0.4
Pyhäjärvi							
Drainage basin	12.9	10.3	17.3	0.8	6.4	51.2	1.2
Nearby catchment	26.5	18.1	17.1	0.0	0.7	33.7	3.9

Table VI. *Morphological data and theoretical water residence time (d) of lakes selected for model validation.*

Lake	Surface area (km^2)	Volume (10^6 m^3)	Mean depth (m)	Max. depth (m)	Theor. residence time (d)
Jämijärvi	9.2	47	5.1	28	121
Keitele	500	3650	7.3	65	797
Kivijärvi	155	740	4.8	41	545
Pieksänjärvi	20.5	40.0	2.0	15	318
Sorsavesi	50.8				
Suontee	149	630	4.2	31	
Ullavanjärvi	15.5	17.05	1.1		
Vesijärvi	40.2	249.6	6.3	39	1825

Table VII. *Data on catchments of lakes.*

Lake	Drainage area (km^2)	Area of nearby catchment (km^2)
Jämijärvi	348	91
Keitele	6265	1421
Kivijärvi	1739	623
Pieksänjärvi	175	79
Sorsavesi	450	167
Suontee	626	385
Ullavanjärvi	141	100
Vesijärvi	221	160

Table VIII. *Land use in drainage basins and nearby catchments of lakes in percentages of total area.*

Lake	Water (%)	Culti-vated area (%)	Open land (%)	Open peatlands and peat pro-duction area (%)	Coniferous dominant peatland (%)	Forest (%)	Built-up area (%)
Jämijärvi							
Drainage basin	2.9	16.9	22.7	3.7	14.4	38.8	0.5
Nearby catchment	8.4	23.7	22.5	0.8	8.2	35.5	1.0
Keitele							
Drainage basin	16.8	3.2	15.6	2.3	9.4	52.4	0.3
Nearby catchment	34.9	3.4	12.6	0.1	1.8	46.6	0.7
Kivijärvi							
Drainage basin	12.4	2.3	19.3	5.5	12.0	48.3	0.2
Nearby catchment	24.4	2.2	13.0	1.1	7.9	51.2	0.3
Pieksänjärvi							
Drainage basin	17.4	3.8	14.5	1.7	15.7	43.4	3.4
Nearby catchment	27.6	2.9	13.3	0.9	11.2	38.8	5.3
Sorsavesi							
Drainage basin	21.3	3.1	14.7	0.4	9.2	50.9	0.2
Nearby catchment	34.9	1.6	11.7	0.1	3.4	47.9	0.3
Suontee							
Drainage basin	24.9	5.0	14.7	0.9	5.0	49.3	0.3
Nearby catchment	36.8	4.0	12.3	0.3	2.0	44.3	0.3
Ullavanjärvi							
Drainage basin	9.6	5.7	16.8	6.6	25.7	35.5	0.2
Nearby catchment	13.1	4.8	15.0	5.2	25.6	36.0	0.2
Vesijärvi							
Drainage basin	17.7	10.0	21.3	0.3	3.0	46.0	1.7
Nearby catchment	23.1	13.0	21.5	0.1	0.9	39.3	2.2

Table IX. *Water chemical data (pH, electrical conductivity, K and colour) and sight depth of lakes at different depths, 1m means one metre below the surface, 2h-1m one metre above the bottom and 2h the average in the whole water column. Values for water chemical parameters refer to the end of the two stratification periods, for smaller lakes annual values are given.*

Lake	pH			Electrical conductivity (mS/m)			K (mg/l)	Colour number (mg Pt/l)			Sight depth (m)
	1m	2h – 1m	2h	1m	2h - 1m	2h		1m	2h - 1m	2h	
Jämijärvi											
March	6.1	6.2	6.2	6.7	8.9	7.9		158			0.8
Mean			6.4			7.1				164	
Keitele											
March	6.7	6.3	6.6	4.2	4.6	4.3	1.0	30	34	32	4.0
August	7.1	6.5	6.9	3.9	4.0	3.9		29	30	30	4.2
Mean	6.9	6.5	6.8	4.1	4.3	4.1	1.0	30	32	31	4.1
Kivijärvi											
March	6.7	6.2	6.5	3.4	3.9	3.5	0.9	43	59	48	3.1
August	6.9	6.4	6.7	3.3	3.4	3.4		51	53	51	2.9
Mean	6.8	6.3	6.6	3.4	3.7	3.5	0.9	47	56	50	3.0
Pieksänjärvi											
March	6.4	6.4	6.4	12.1	13.1	12.6		43	49	47	2.3
August	7.1	6.9	7.0	7.8	8.0	7.9		40	39	40	2.0
Mean	6.8	6.7	6.7	10.0	10.6	10.3		42	44	44	2.2
Sorsavesi											
March	6.5	6.0	6.4	3.6	3.9	3.7	0.9	24	24	25	5.4
August	6.9	6.2	6.6	3.6	3.6	3.6		27	29	28	4.9
Mean	6.7	6.1	6.5	3.6	3.8	3.7	0.9	26	27	27	5.2
Suontee											
March	6.8	6.2	6.6	4.8	5.1	5.0		9	10	9	7.7
August	7.2	6.3	6.8	4.6	4.7	4.7		8	9	9	6.1
Mean	7.0	6.3	6.7	4.7	4.9	4.9		9	10	9	6.9
Ullavanjärvi											
March	6.0			5.2				251			
Mean			6.1			5.0				254	
Vesijärvi											
March	6.7	6.6	6.6	6.6	8.7	7.2	1.6	14	70	29	5.7
August	7.1	6.3	6.7	6.6	7.3	6.8		14	27	18	3.2
Mean	6.9	6.5	6.7	6.6	8.0	7.0	1.6	14	49	24	4.5

Table X. *Seasonal variations in water chemical data (oxygen and saturation % of oxygen, total P and total N, and chlorophyll a) at different depths, 1m means one metre below the surface, 2h-1m one metre above the bottom and 2h the average in the whole water column.*

Lake	Oxygen (mg/l)			Oxygen saturation (%)			Tot.P (µg/l)			Tot.N (µg/l)			Chloro phyll a (µg/l)
	1m	2h-1m	2h	1m	2h-1m	2h	1m	2h-1m	2h	1m	2h-1m	2h	0-2m
Jämijärvi													
March	9.3	3.5	6.6	65	25	47	69	116	91	1257	1641	1461	
Mean			5.9			51			79			1225	20.5
Keitele													
March	13.2	3.8	10.1	91	29	72	8	14	9	448	439	430	
August	8.9	7.5	8.5	91	66	81	9	9	9	375	442	394	
Mean	11.1	5.7	9.3	91	48	77	9	12	9	412	441	413	5.3
Kivijärvi													
March	12.6	3.6	9.6	88	27	69	9	18	10	425	440	427	
August	8.9	7.3	8.1	90	65	77	10	11	10	404	494	441	
Mean	10.7	5.5	8.9	89	46	73	10	15	10	415	467	434	4.8
Pieksänjärvi													
March	5.0	3.9	4.5	36	28	32	16	17	16	2057	2529	2206	
August	8.9	7.3	8.4	91	74	85	20	22	20	726	773	712	
Mean	7.0	5.6	6.5	64	51	59	18	20	18	1392	1651	1459	7.3
Sor-savesi													
March	12.7	3.8	9.3	88	29	68	4	7	5	413	316	350	
August	8.8	7.4	8.1	89	61	72	4	5	5	303	354	321	
Mean	10.8	5.6	8.7	89	45	70	4	6	5	358	335	336	3.7
Suontee													
March	13.0	3.0	9.7	91	22	70	4	6	5	358	379	354	
August	9.3	5.0	7.6	96	44	74	4	8	6	321	483	377	
Mean	11.2	4.0	8.7	94	33	72	4	7	6	340	431	366	3.6
Ullavanjärvi													
March	4.6			33			40			934			
Mean			4.7			37			51			889	12.9
Vesijärvi													
March	12.4	0.8	8.3	87	6	60	9	120	38	417	936	530	
August	9.1	2.0	5.7	95	16	54	13	47	24	351	707	483	
Mean	10.8	1.4	7.0	91	11	57	11	84	31	384	822	507	8.0

4 LAKES SELECTED FOR MODEL VALIDATION

An independent set of eight lakes, representing different lake types, typical of northern Europe, was established for validation of the model. Four of the lakes are oligotrophic, two eutrophic and two mesotrophic. Average depositions in the municipalities at the outlets of the lakes were between 12 and 44 kBq/m^2.

Morphological and water chemical parameters and information on the catchments of the lakes are given also for these lakes. In area, the lakes ranged from 9.2 to 500 km^2 and in average depth from 1.1 to 7.3 m (Tables VI - IX).

The trophic status of the lakes, based on concentrations of total phosphorus and chlorophyll a (cf. Table X), and the average deposition of ^{137}Cs in 1986 in the municipality at the outlet of the lake, are as follows:

	Trophic status	**^{137}Cs, kBq/m^2**
Jämijärvi	Eutrophic	29
Keitele	Oligotrophic	40.6
Kivijärvi	Oligotrophic	34.8
Pieksänjärvi	Mesotrophic	43.5
Sorsavesi	Oligotrophic	23.2
Suontee	Oligotrophic	11.6
Ullavanjärvi	Eutrophic	17.4
Vesijärvi	Mesotrophic	43.5

5 ^{137}Cs IN FISH

The lakes differ from each other in terms of temporal changes in *^{137}Cs in different types of fish*: predatory, non-predatory and intermediate (Fig. 2). Non-predatory species reach maximum values of ^{137}Cs soon after the deposition but predatory species not until two or three years afterwards (Saxén 1996, Saxén 1992, Saxén 1990, Saxén 1987). This has to be taken into account in the *fish model.* The highest annual averages of ^{137}Cs, > 20000 Bq/kg (fresh weight), were found in an oligotrophic lake and in a small mesotrophic lake with long water residence times.

The variation in activity concentrations of ^{137}Cs in various types of fish in various lakes is largest in intermediate and especially in predatory fish during the first four years after the deposition (Fig. 2). Non-predatory fish from various lakes had the lowest variation (Fig. 2). One explanation to this is that one sample of non-predatory fish consists of several (generally more than 10) individuals, while samples of intermediate and especially of predatory fish include only a few individuals, sometimes only one big-sized fish.

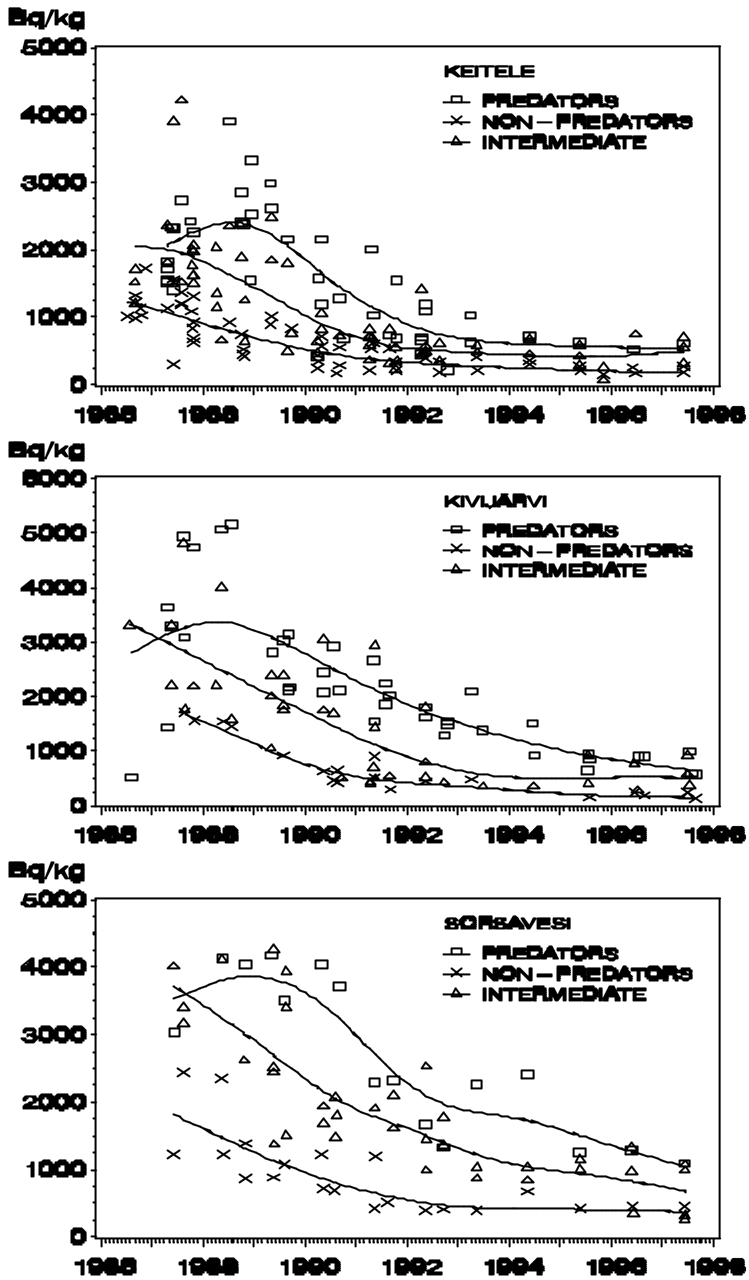


Figure 2a. *Changes in* ^{137}*Cs (Bq/kg fresh weight) in the three fish types: predatory, non-predatory and intermediate in lakes Keitele, Kivijärvi and Sorsavesi in 1986–1997.*

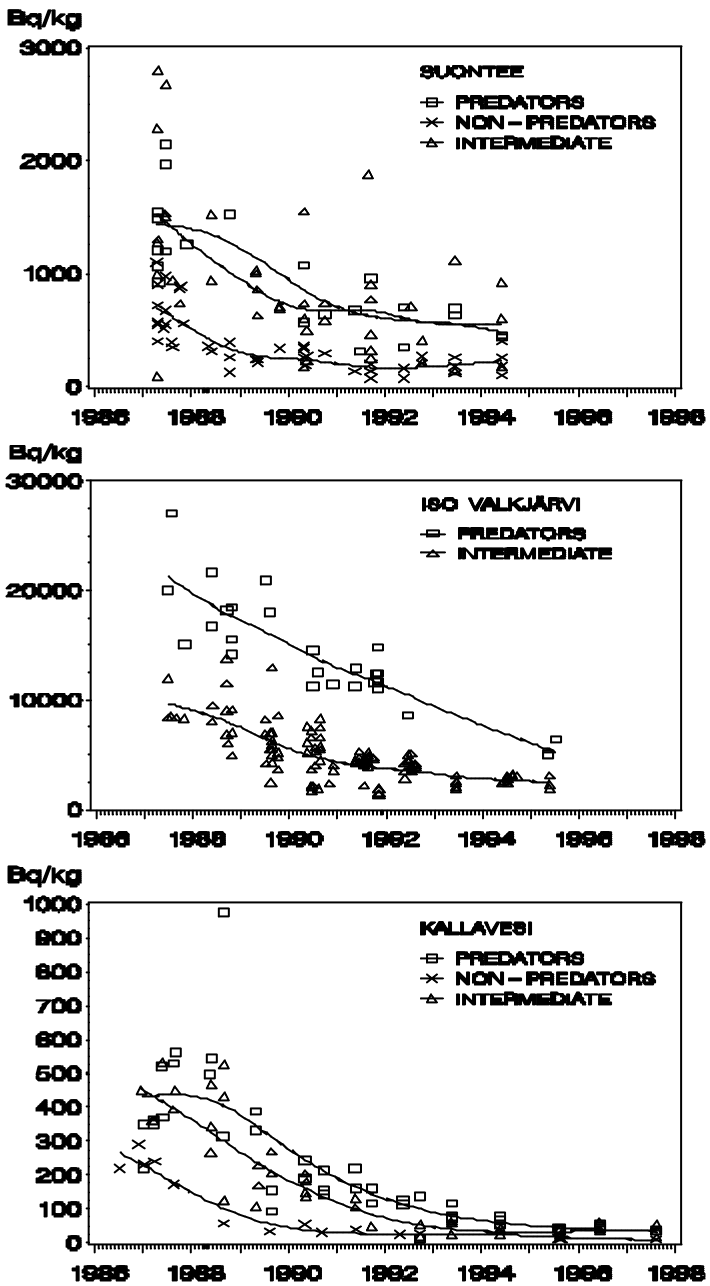


Figure 2b. Changes in ^{137}Cs (Bq/kg fresh weight) in the three fish types: predatory, non-predatory and intermediate in lakes Suontee, Iso Valkjärvi and Kallavesi in 1986–1997.

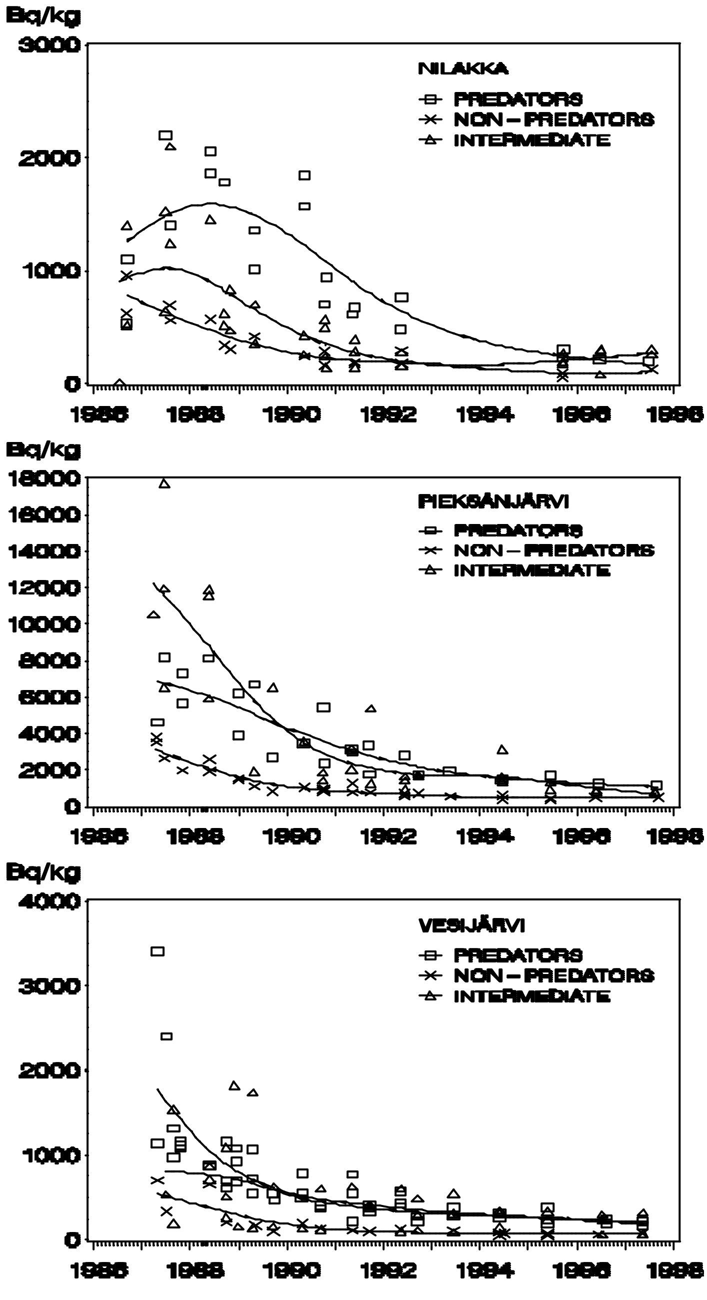


Figure 2c. Changes in ^{137}Cs (Bq/kg fresh weight) in the three fish types: predatory, non-predatory and intermediate in lakes Nilakka, Pieksänjärvi and Vesijärvi in 1986–1997.

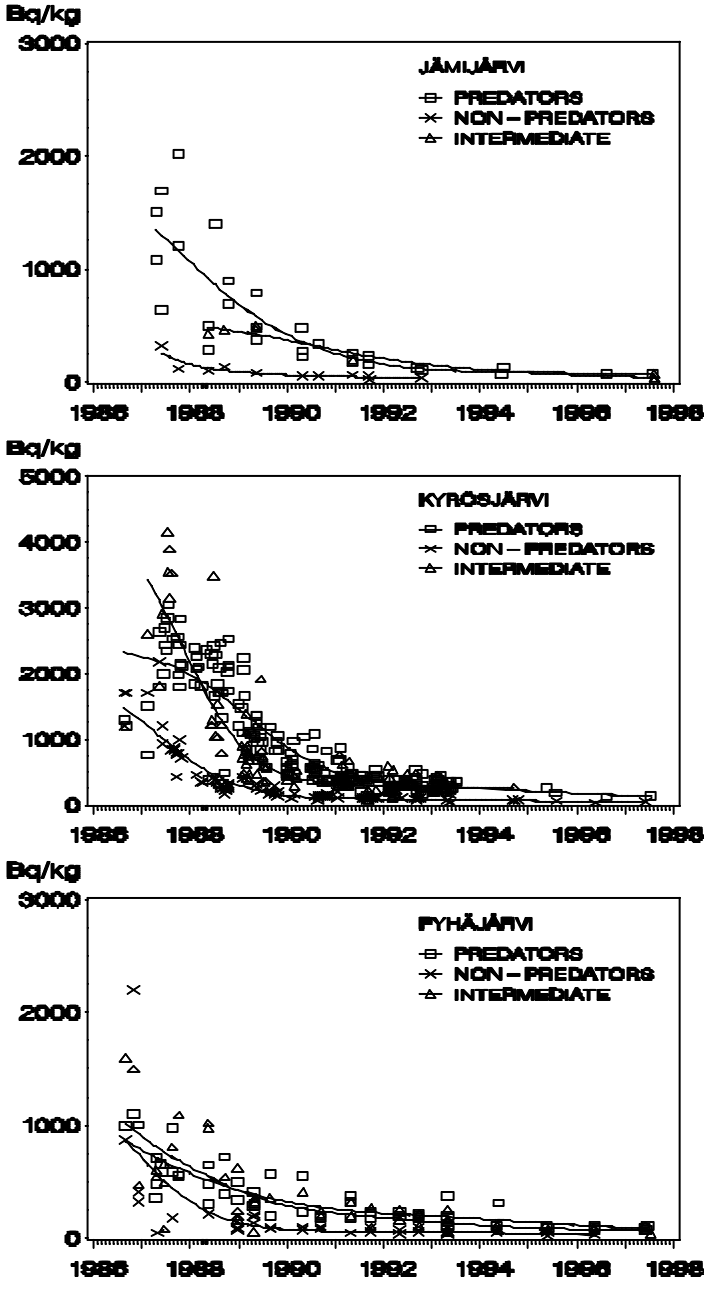


***Figure 2d**. Changes in ^{137}Cs (Bq/kg fresh weight) in the three fish types: predatory, non-predatory and intermediate in lakes Jämijärvi, Kyrösjärvi and Pyhäjärvi in 1986–1997.*

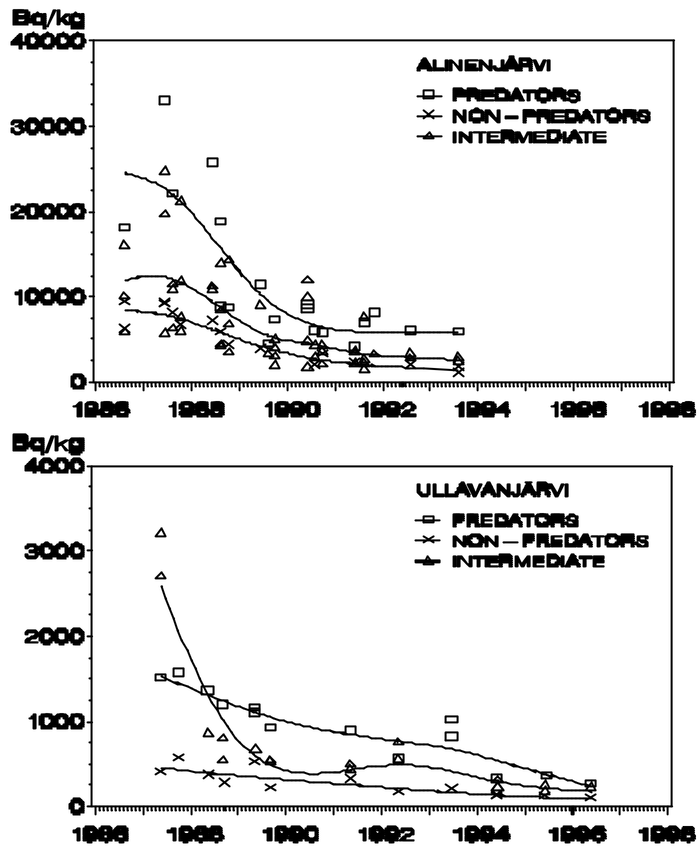


Figure 2e. Changes in ^{137}Cs (Bq/kg fresh weight) in the three fish types: predatory, non-predatory and intermediate in lakes Alinenjärvi and Ullavanjärvi in 1986–1997.

6 TRANSFER COEFFICIENTS OF ^{137}Cs FROM DEPOSITION TO FISH

The transfer coefficients (TF) with variations for the three fish types in 1986-1997 vary considerably between lakes (Figs. 3 and 4). The transfer of ^{137}Cs into fish is in general higher in an oligotrophic than a eutrophic lake. Some other factor, however, also cause high transfer as, for instance, in Lake Iso Valkjärvi, a mesotrophic lake where the high transfer coefficients (0.28 for non-predators and 0.6 for predators in 1987) (Fig. 3e) are due to the fact that the lake has neither inlets nor outlets and hence a very long water residence time. Additionally, this lake is slightly acidic which is why no roaches exist in the lake.

In eutrophic lakes the averages of transfer coefficients in predators, e.g., during 1987-1988, were about 0.04 m^2/kg, while the respective figure for predators in oligotrophic lakes in 1988 was about 0,1 m^2/kg. Variations in annual averages are large in all lake groups and fish types as shown in figure 5. Hence the variation ranges of TFs for the three fish types in various lake types partly overlap each other (Fig. 5).

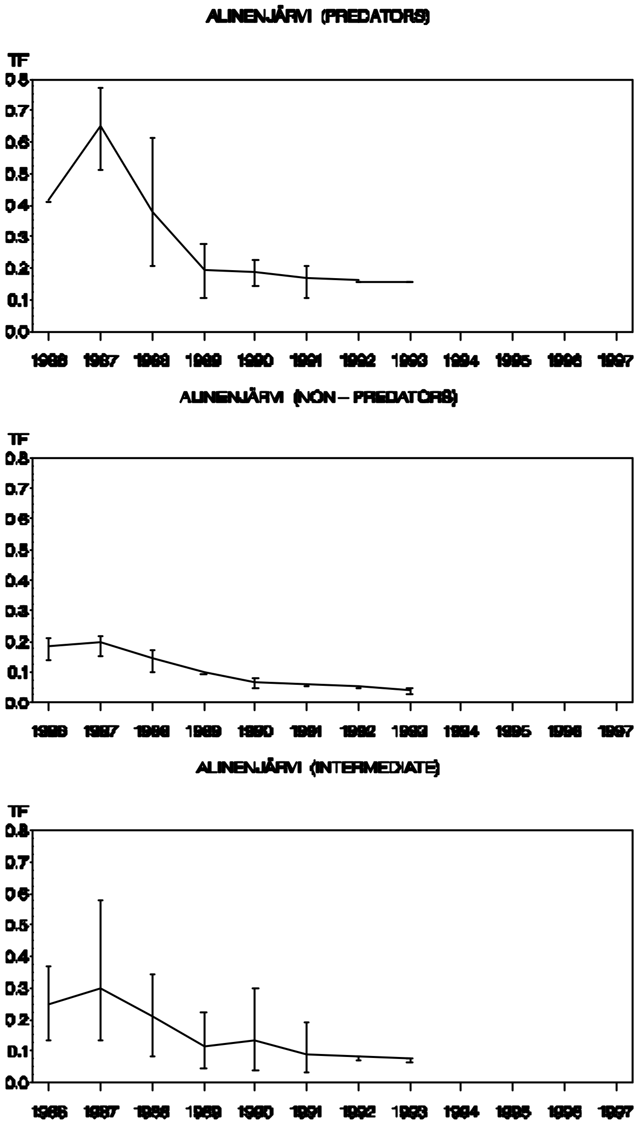


Figure 3a. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh

weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Alinenjärvi in 1986–1997.

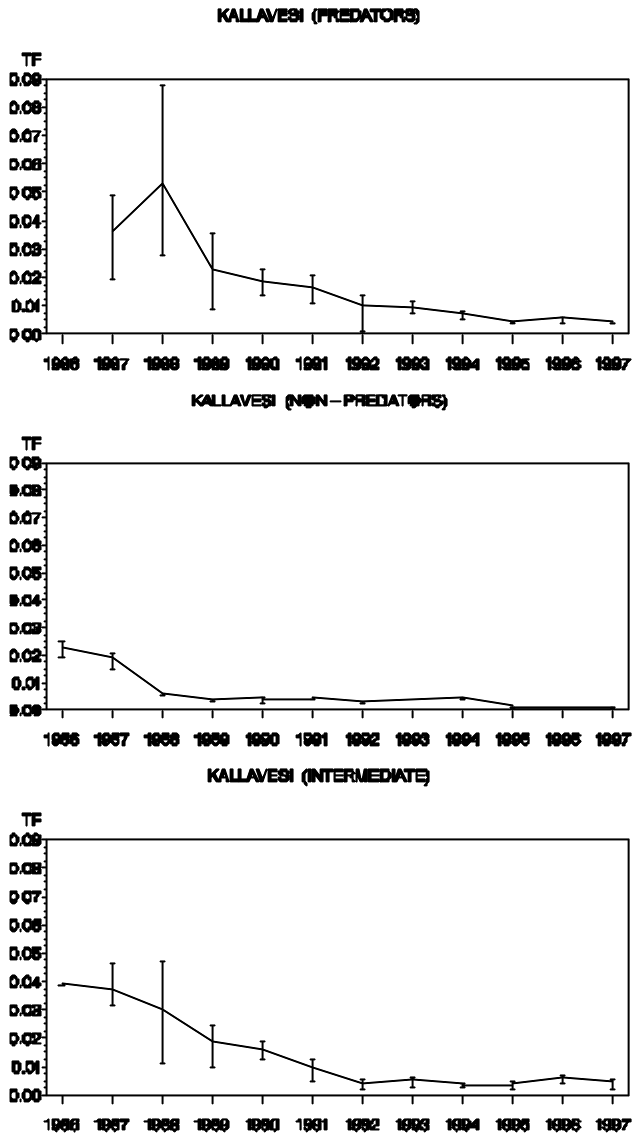


Figure 3b. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh

weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Kallavesi in 1986–1997.

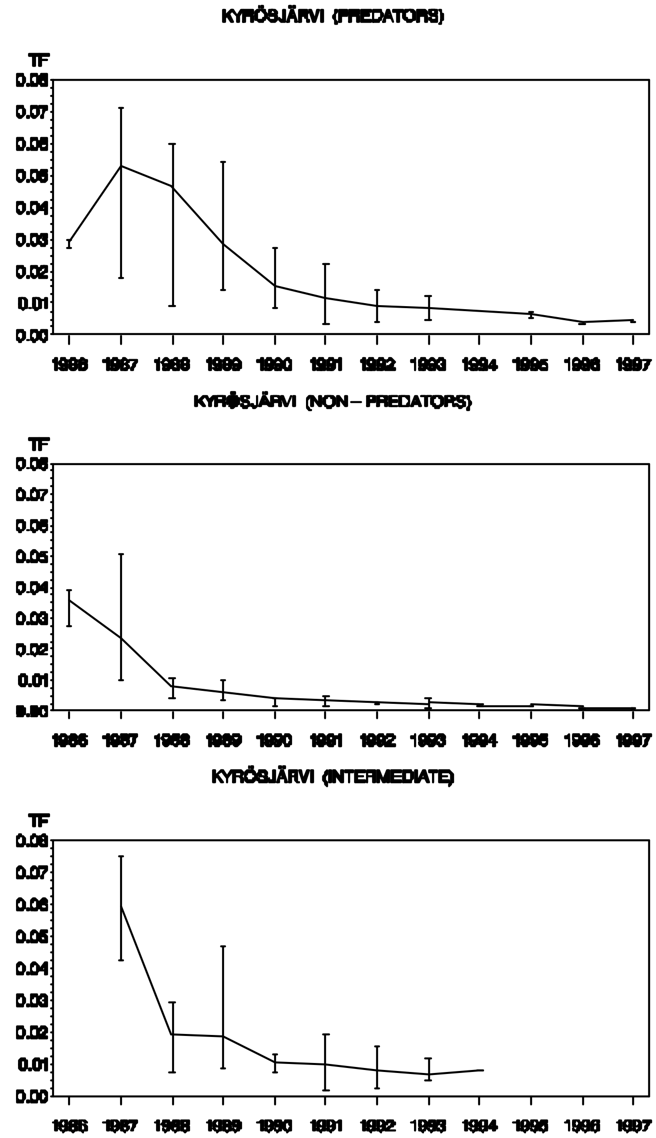


Figure 3c. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs / kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Kyrösjärvi in 1986-1997.

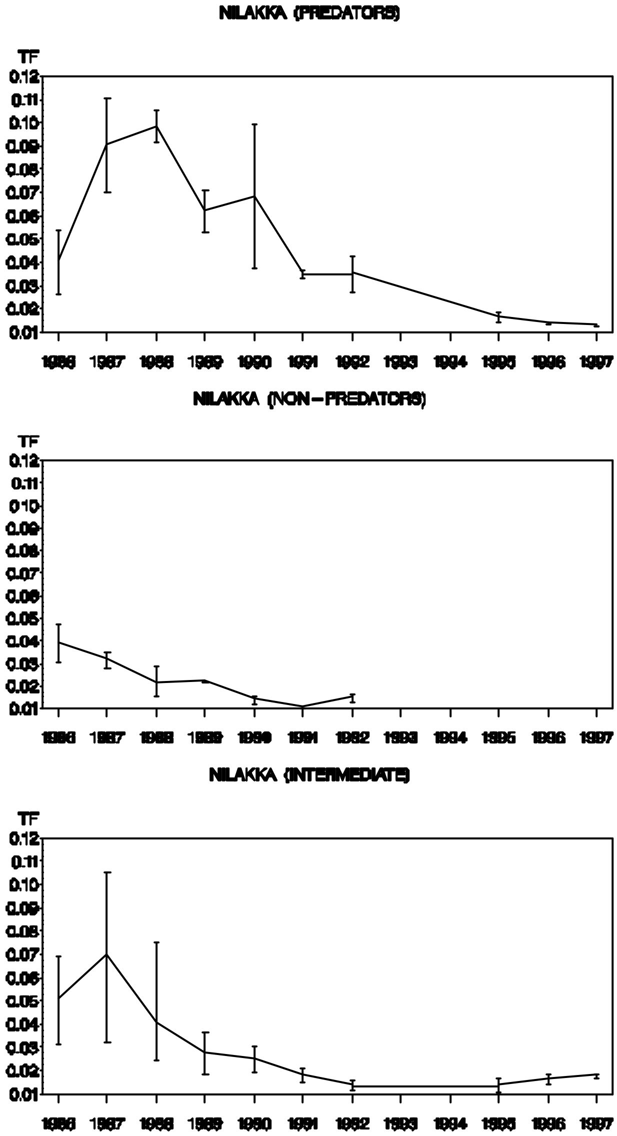


Figure 3d. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for* ^{137}Cs *(Bq* ^{137}Cs */kg fresh weight in fish: Bq* ^{137}Cs */*m^2 *deposited) with variation in Lake Nilakka in 1986-1997.*

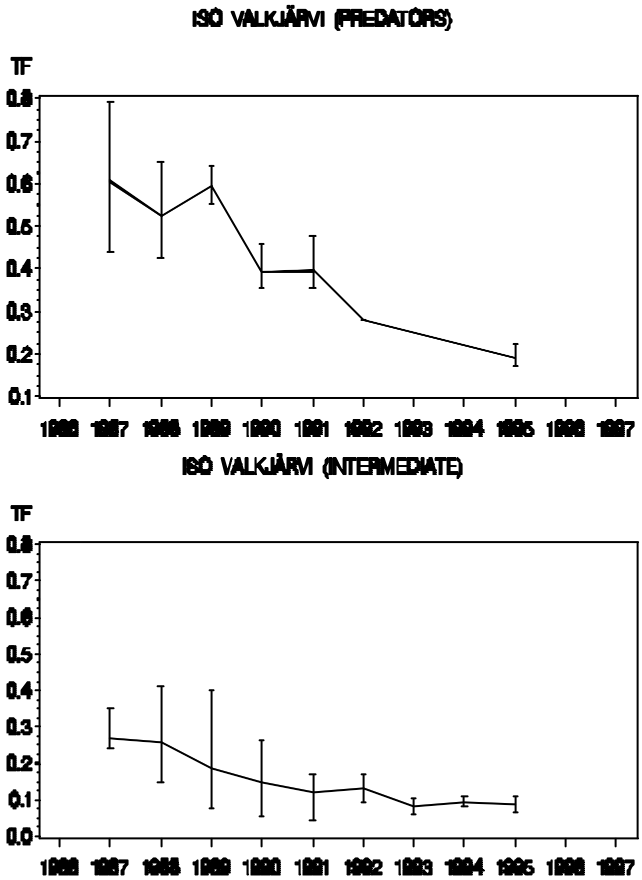


Figure 3e. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Iso Valkjärvi in 1986-1997.

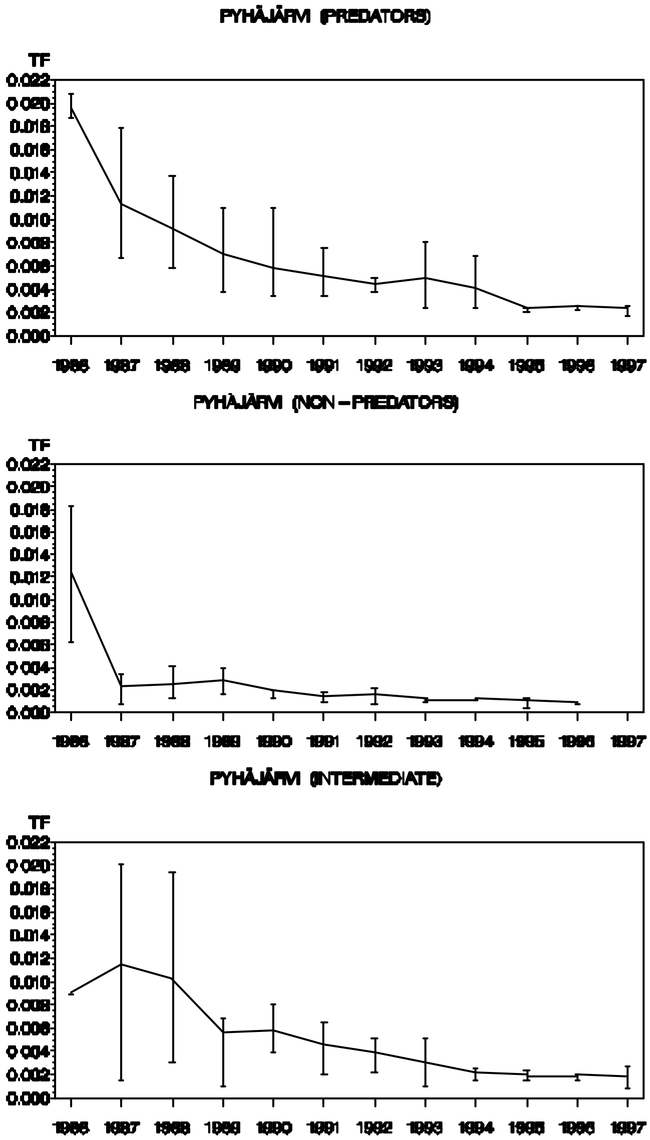


Figure 3f. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Pyhäjärvi in 1986 – 1997.

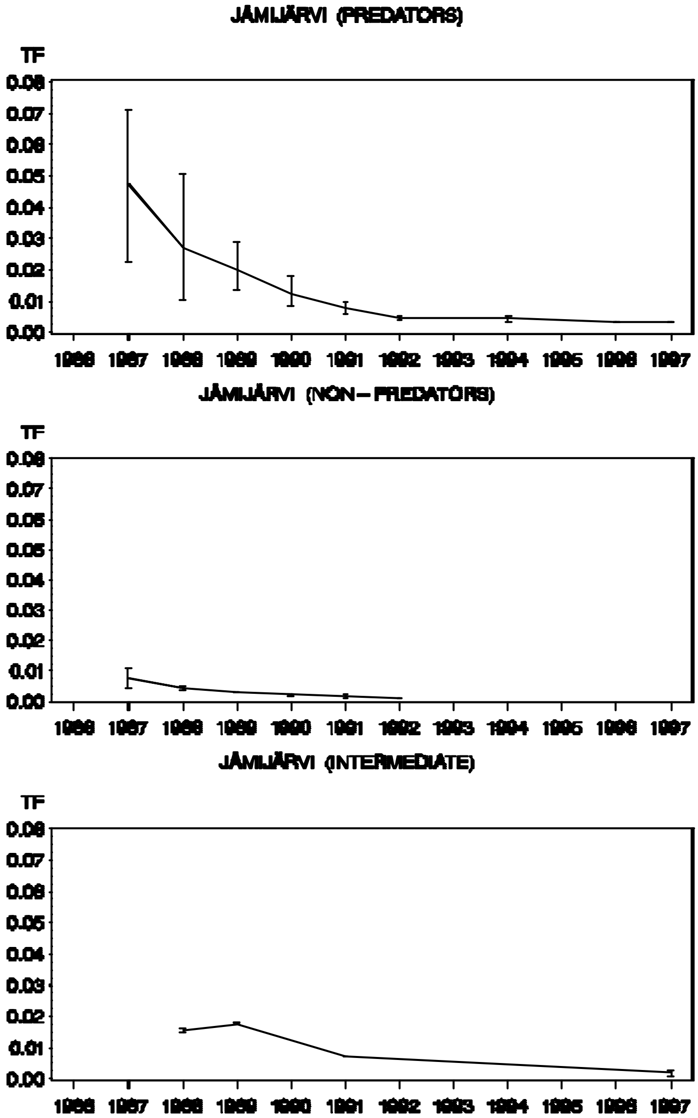


Figure 4a. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Jämijärvi in 1986–1997.

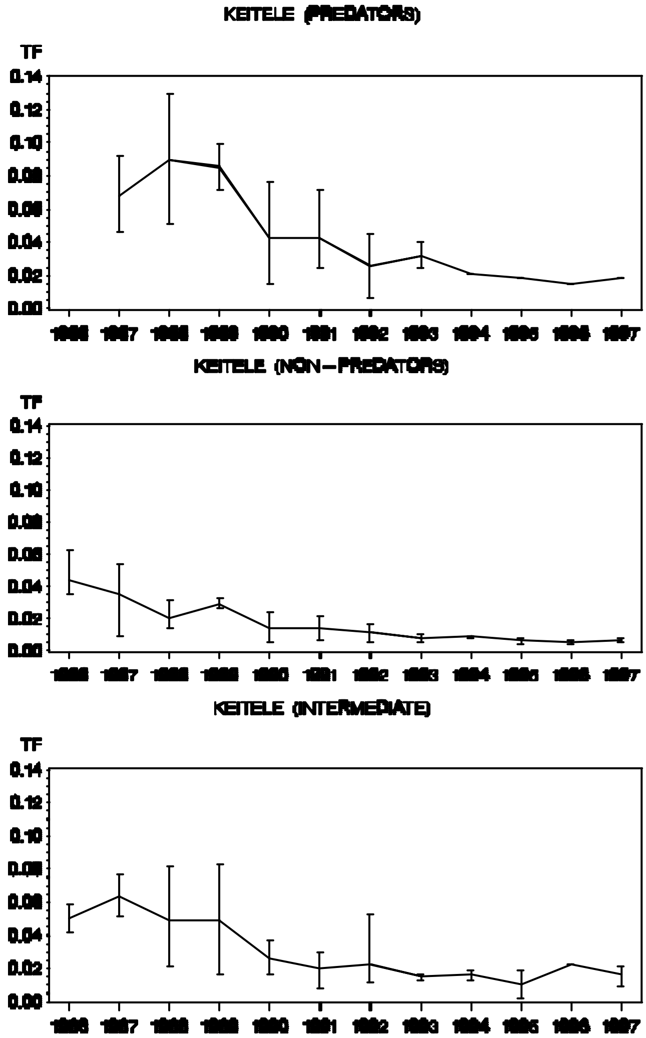


Figure 4b. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs /m^2 deposited) with variation in Lake Keitele in 1986–1997.

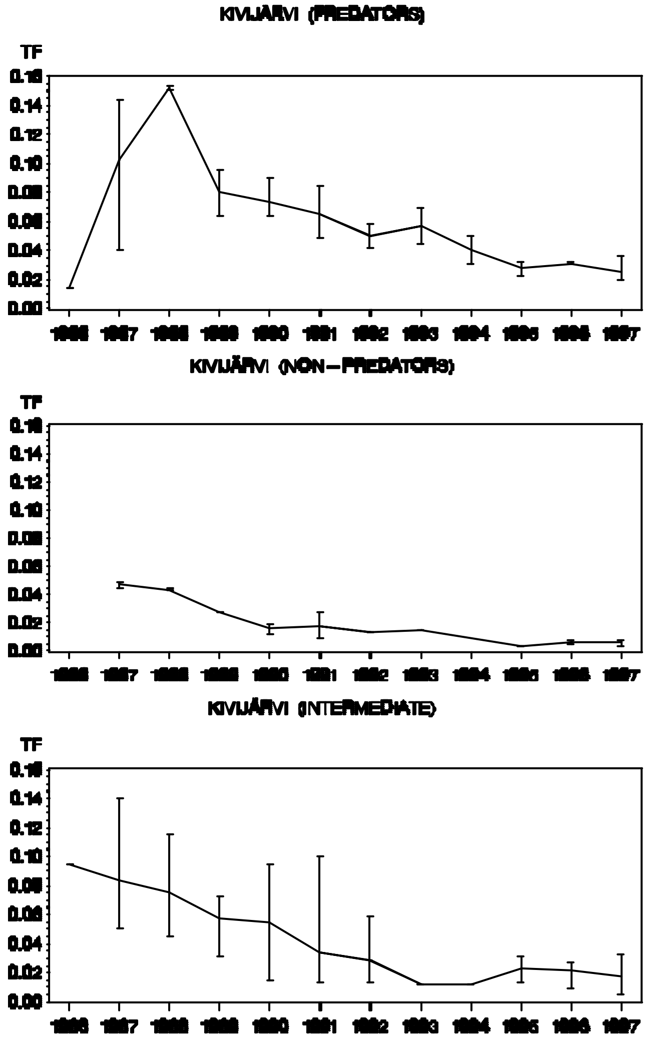


Figure 4c. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs /m^2 deposited) with variation in Lake Kivijärvi in 1986–1997.

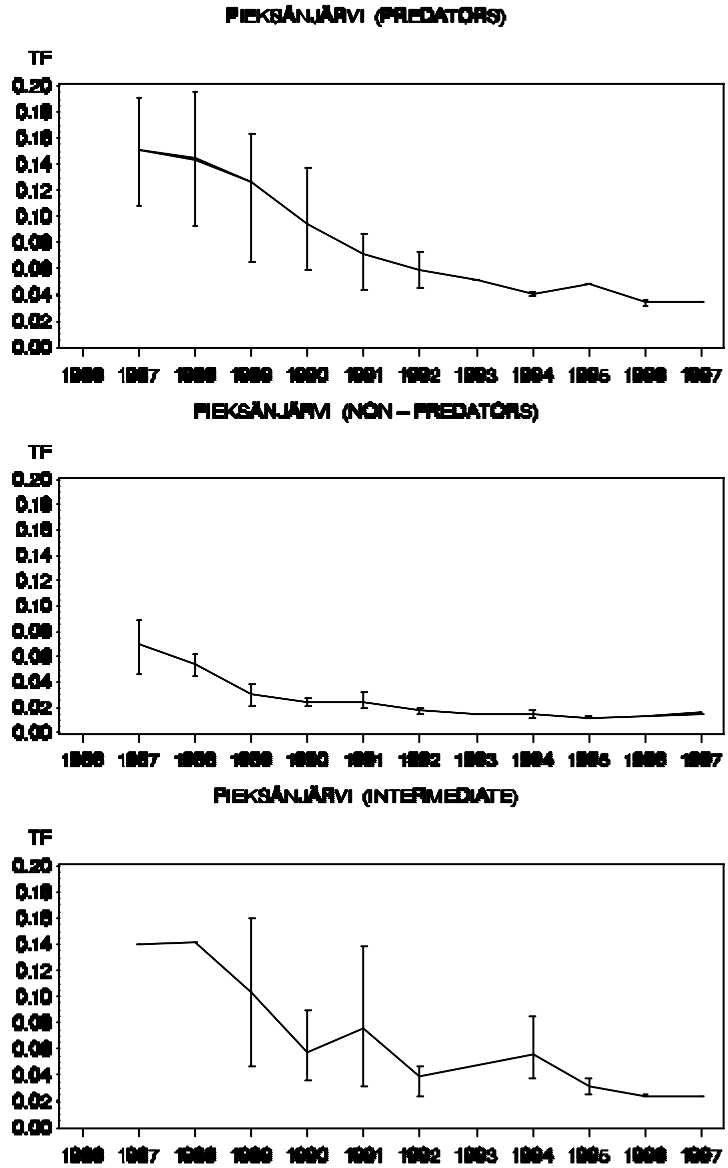


Figure 4d. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for* ^{137}*Cs (Bq* ^{137}*Cs / kg fresh weight in fish: Bq* ^{137}*Cs / m*^{2} *deposited) with variation in Lake Pieksänjärvi in 1986–1997.*

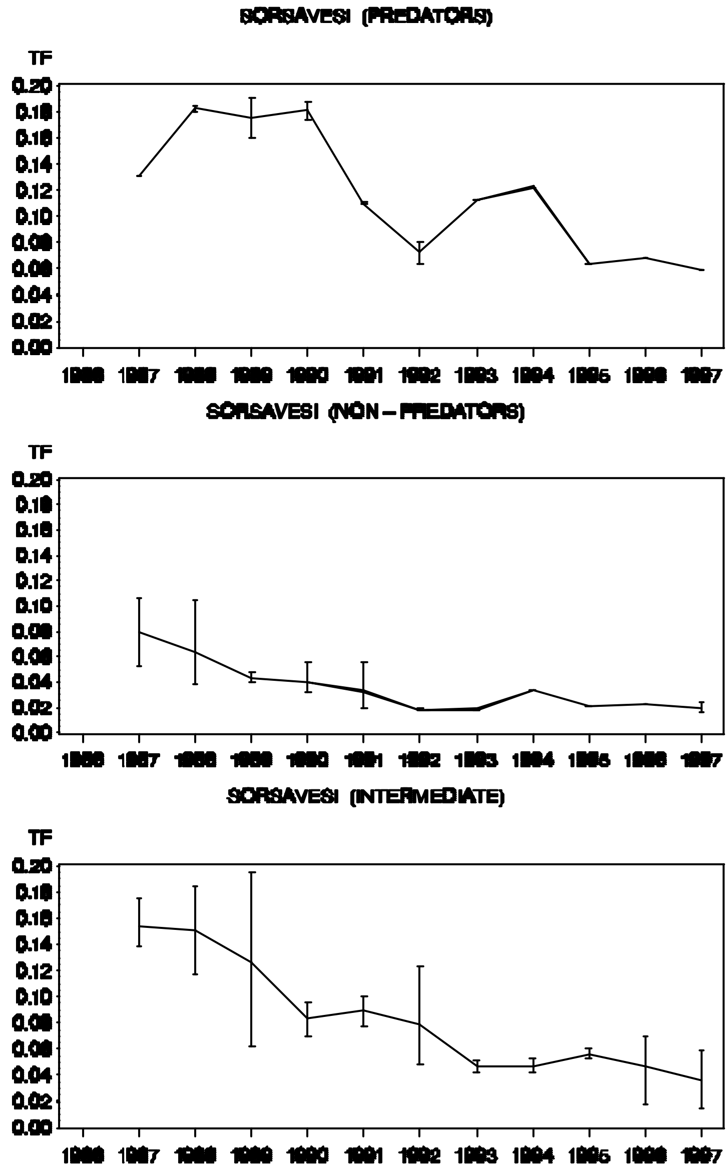


Figure 4e. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs / kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Sorsavesi in 1986–1997.*

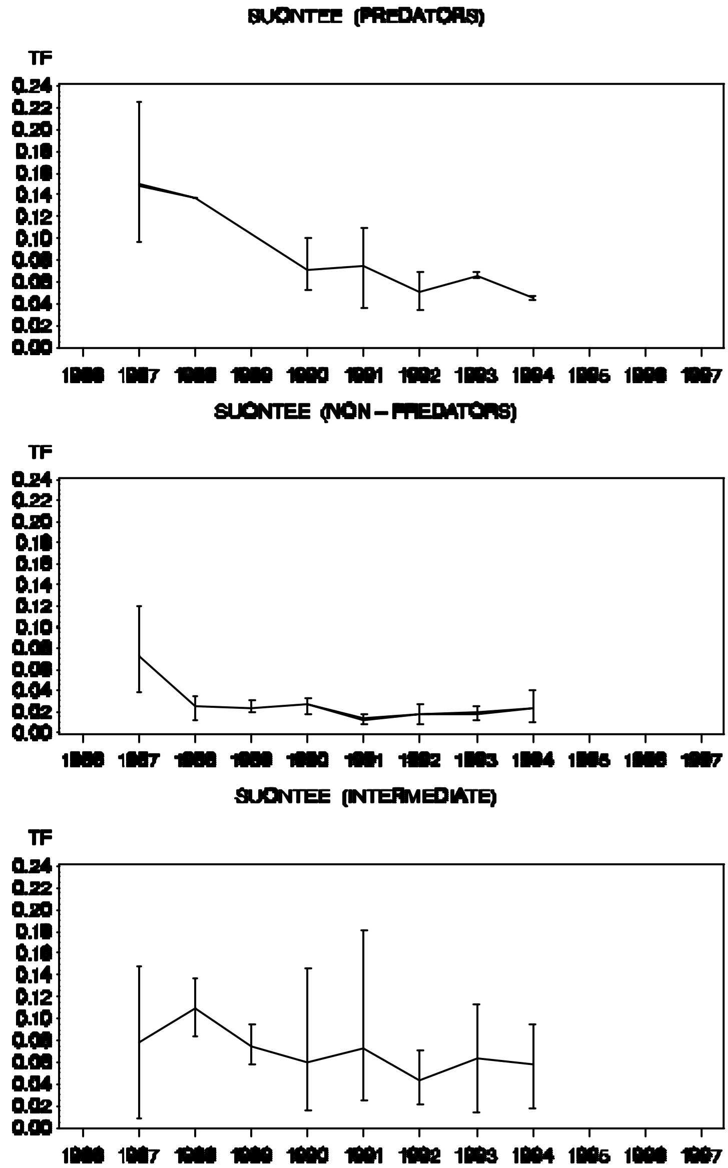


Figure 4f. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs /m^2 deposited) with variation in Lake Suontee in 1986–1997.*

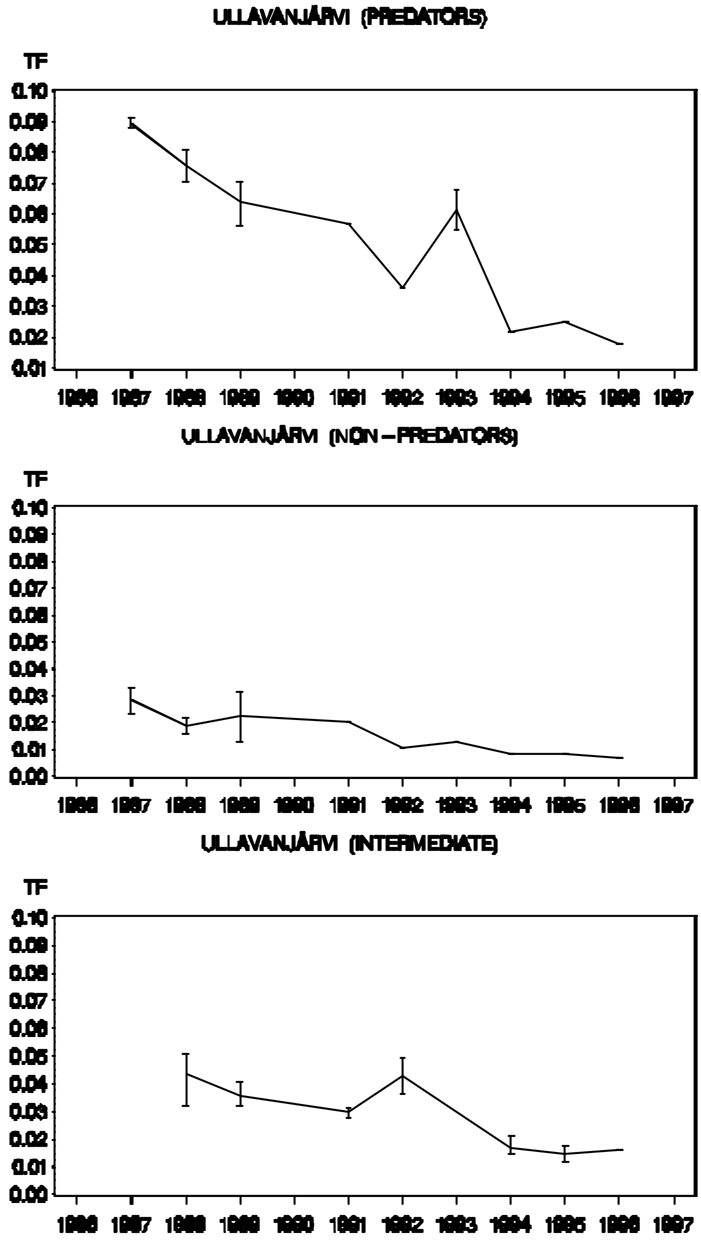


Figure 4g. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermedite fish for ^{137}Cs (Bq ^{137}Cs / kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) with variation in Lake Ullavanjärvi in 1986–1997.*

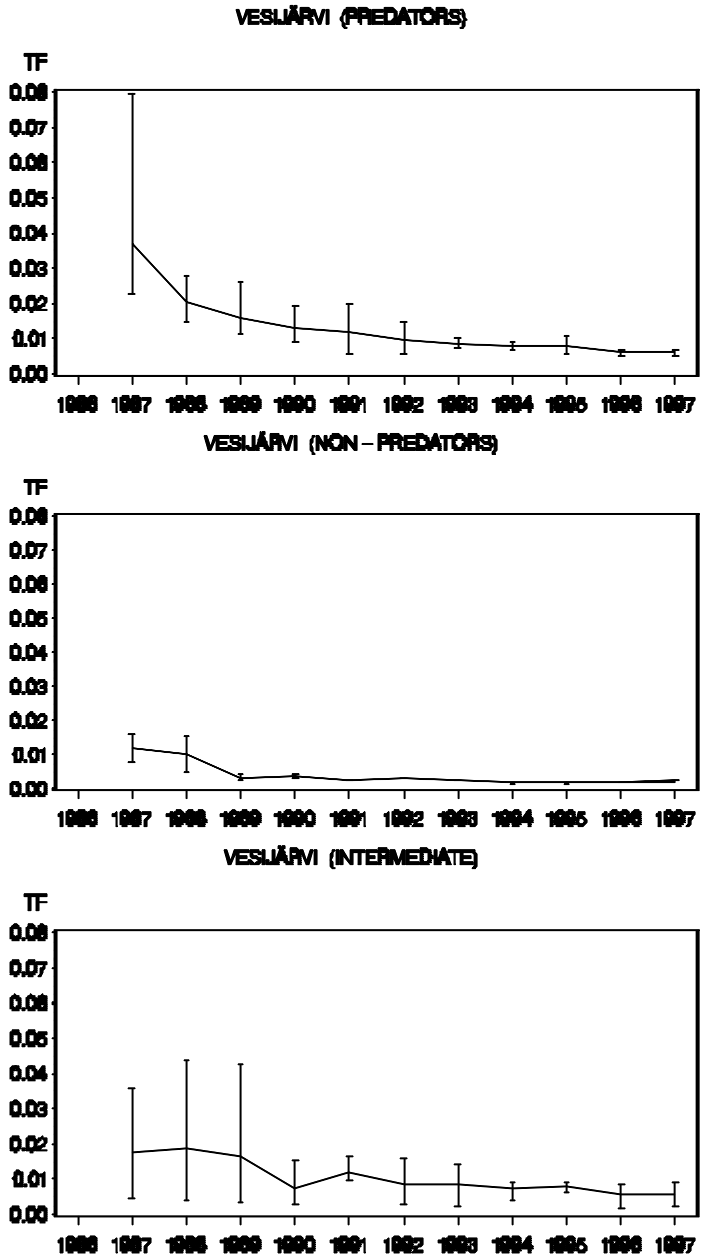


Figure 4h. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish for ^{137}Cs (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs / m^{2} deposited) with variation in Lake Vesijärvi in 1986–1997.*

7 CORRELATION OF TFs WITH CERTAIN WATER CHEMICAL PARAMETRES

The correlation of various individual parameters with ^{137}Cs in fish per unit deposition (TF) was also studied using the data for 1988. The inverse correlation with the potassium content in lake water observed in earlier studies (Kolehmainen 1968) was found here, too (r^2 between 0.66 - 0.72, Fig. 6.). The correlation of electrical conductivity with TFs was moderately high (r^2 between 0.45 and 0.56) when one lake (Pieksänjärvi) was excluded (Fig. 7).

The correlation of TFs with total phosphorus and chlorophyl a, which together determine the trophic class of the lake, was also noted, but the correlation coefficients were lower (r^2 between 0.15 and 0.46) than those with the potassium concentration and electrical conductivity (Figs. 8 and 9).

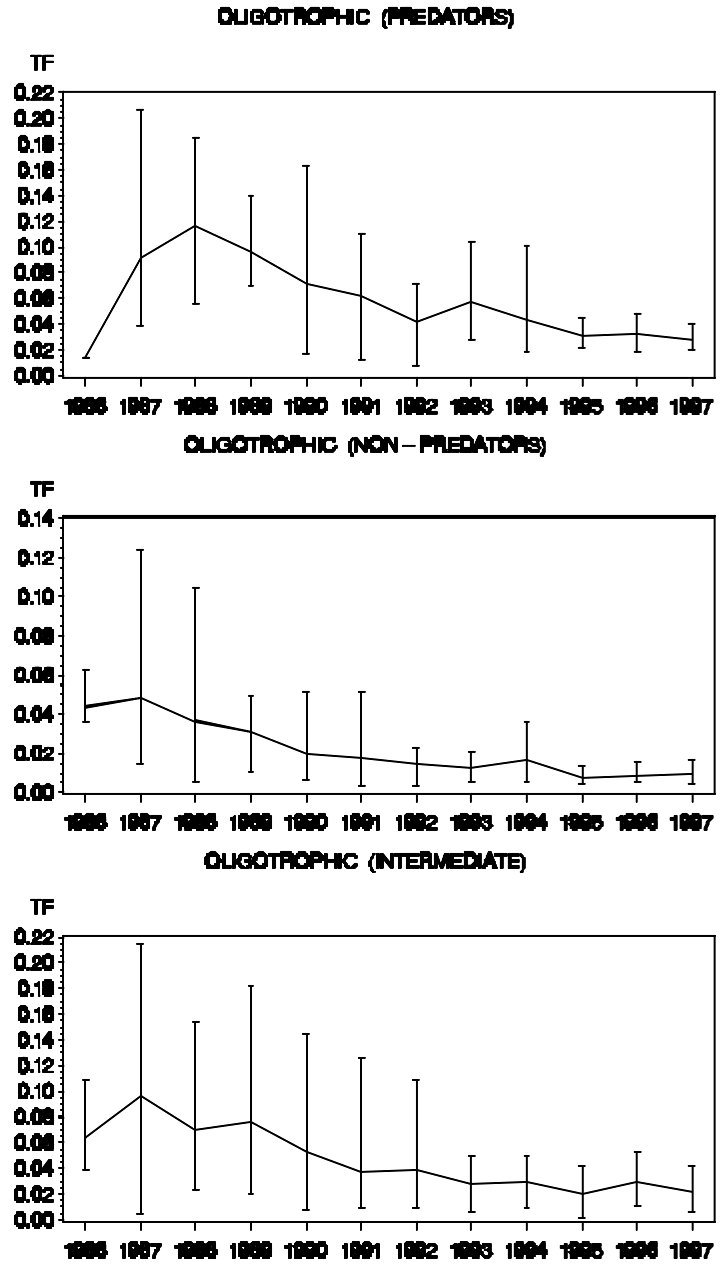


Figure 5a. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish with variation (Bq ^{137}Cs /kg fresh weight in fish: Bq ^{137}Cs / m^{2} deposited) in oligotrophic lakes of this study in 1986-1997.*

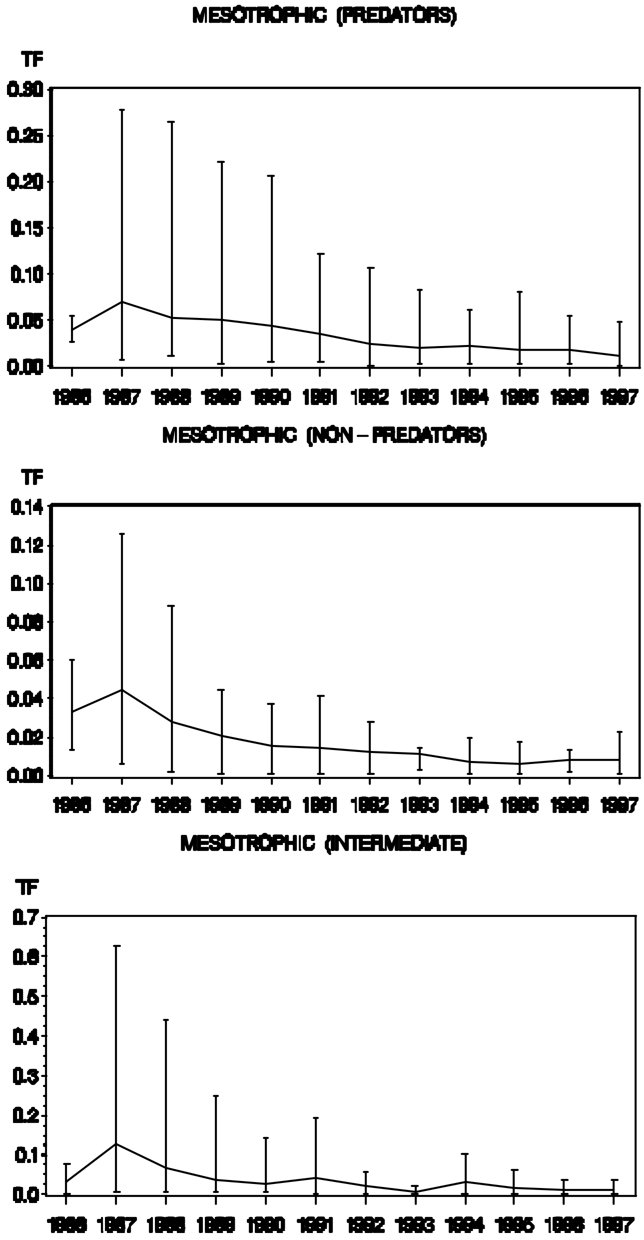


Figure 5b. *Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish with variation (Bq ^{137}Cs / kg fresh weight in fish: Bq ^{137}Cs / m^2 deposited) in mesotrophic lakes of this study*

(besides Lake Iso Valkjärvi, which differs most from the other lakes of this group, cf. Fig. 3e) in 1986-1997.

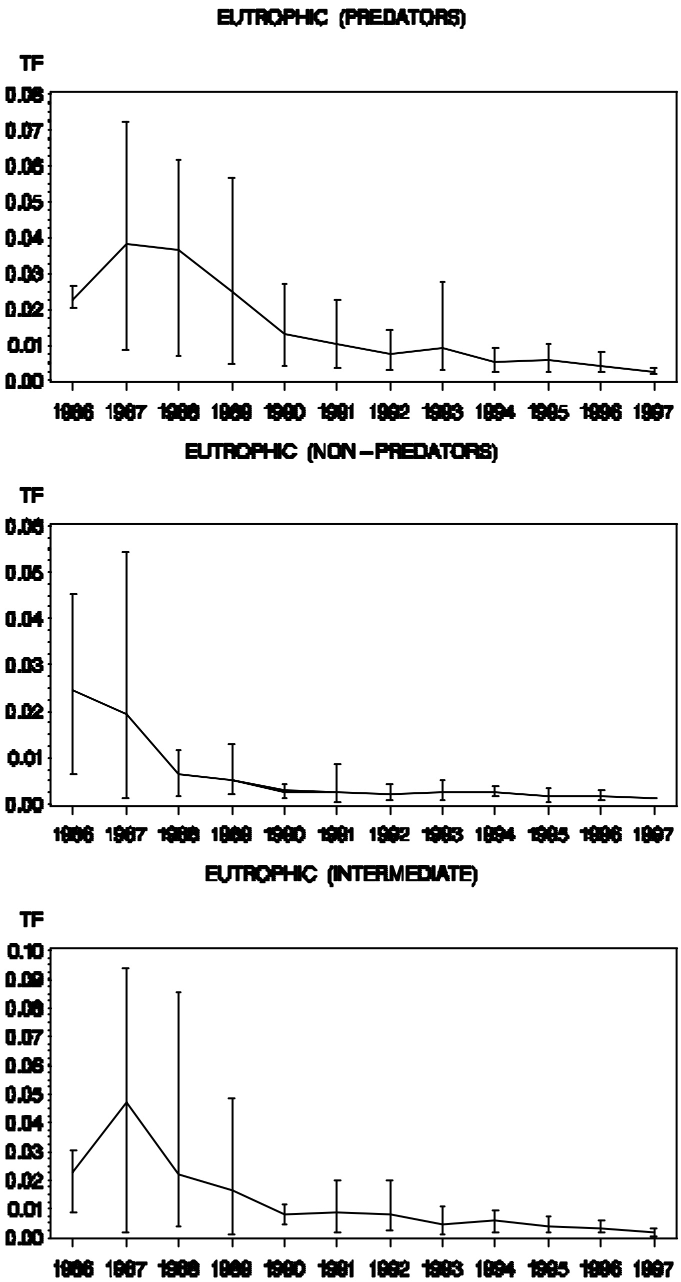


Figure 5c*. Annual averages of transfer coefficients (TF) from deposition to predatory, non-predatory and intermediate fish with variation (Bq ^{137}Cs /kg*

fresh weight in fish: Bq ^{137}Cs / m^2 deposited) in eutrophic lakes of this study in 1986-1997.

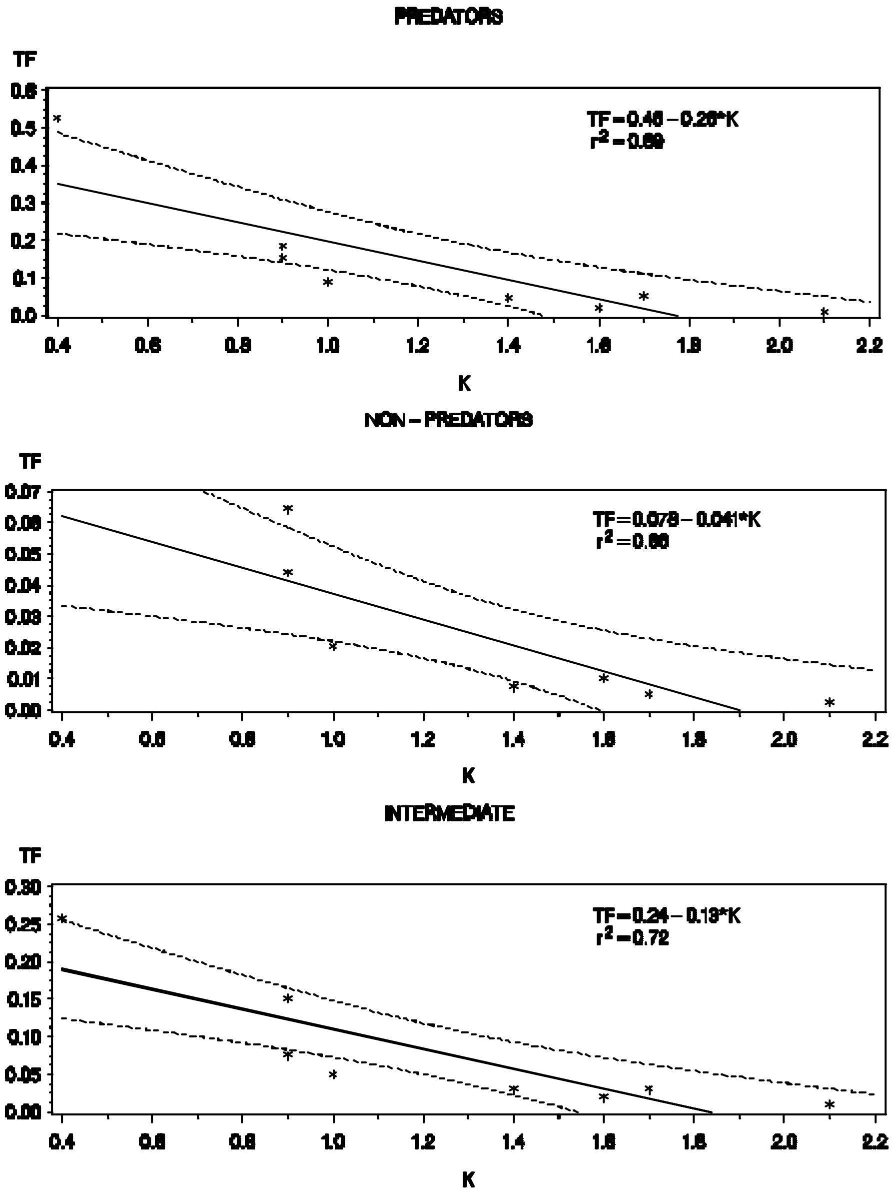


Figure 6*. Correlation of ^{137}Cs in predatory, non-predatory and intermediate fish per unit deposition (TF) with potassium concentration of water in 1988.*

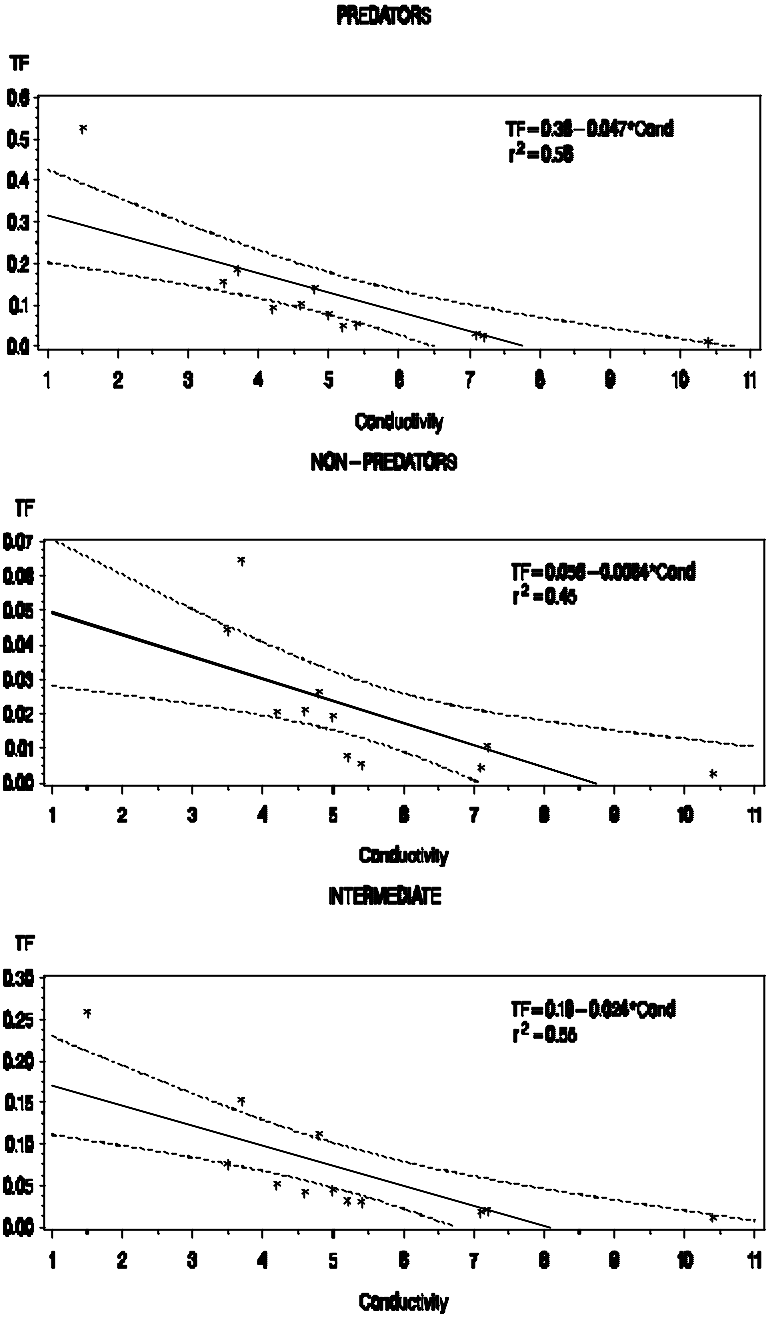


***Figure 7**. Correlation of ^{137}Cs in predatory, non-predatory and intermediate fish per unit deposition (TF) with electrical conductivity in 1988.*

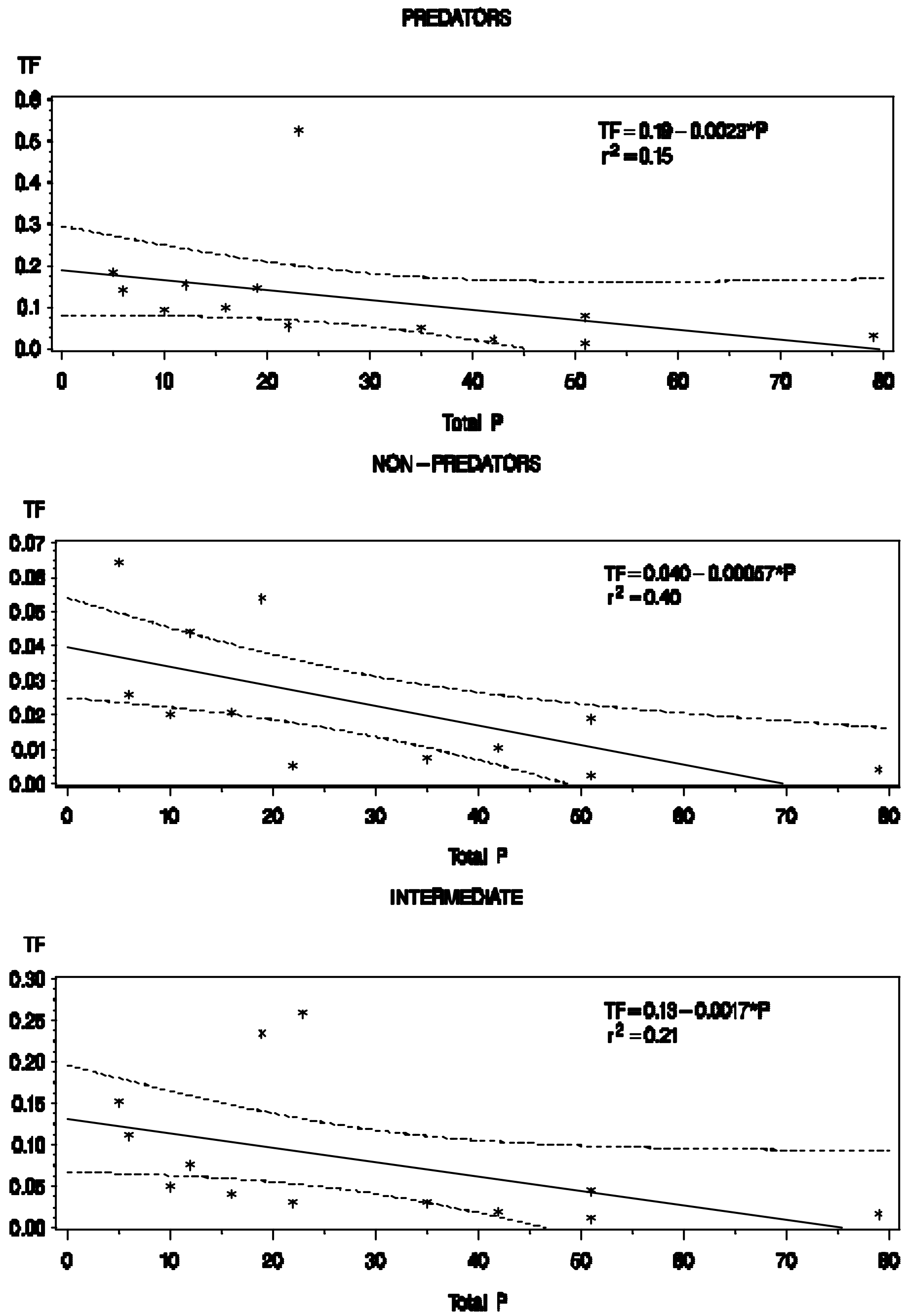
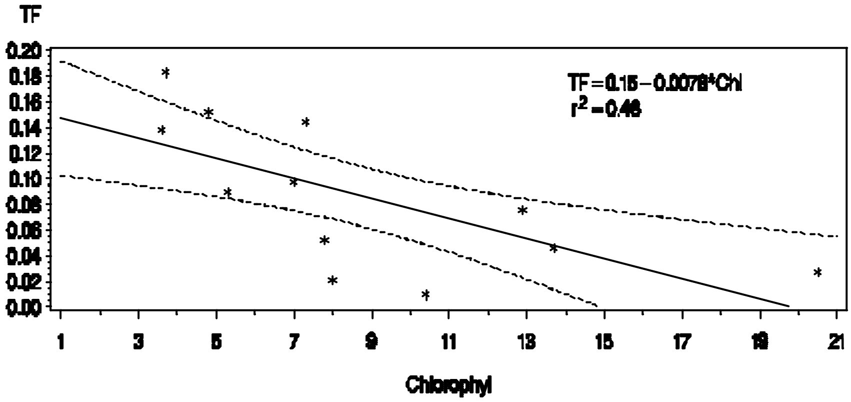
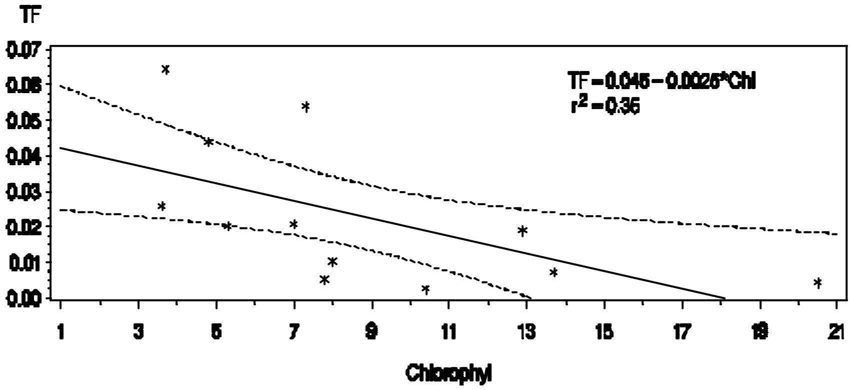


Figure 8. *Correlation of ^{137}Cs in predatory, non-predatory and intermediate fish per unit deposition (TF) with total phosphorus of water in 1988.*

PREDATORS



NON−PREDATORS



INTERMEDIATE

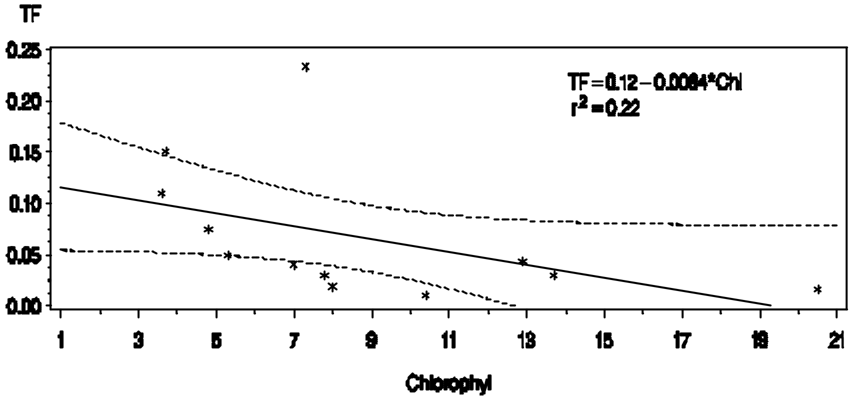


Figure 9. *Correlation of ^{137}Cs in predatory, non-predatory and intermediate fish per unit deposition (TF) with chlorophyl a of water in 1988.*

8 DISCUSSION

A number of factors control the transfer of radio-caesium from deposition to fish. The factors may differ in the directions of their effects and thus cancel or mitigate each other.

After a deposition occasion, the transfer of ^{137}Cs into fish is most easily described by a transfer coefficient (Figs. 3 - 5). This coefficient includes the simultaneous influence of all the factors affecting the transfer in the pathway from deposition into fish. Time-dependent transfer coefficients as such can be regarded as a kind of a lake-specific model. If deposition to the lake is known, the activity concentrations in fish can be estimated within specific uncertainty limits, by multiplying the deposition value by the transfer coefficient at a certain time point. Temporal changes in annual averages of transfer coefficients with variation are given here for a certain set of lakes and for three lake types oligotrophic, eutrophic and mesotrophic, because one of the factors strongly affecting the transfer of ^{137}Cs into fish is the nutrition level of the lake.

The average transfer of ^{137}Cs in predators at the time of maximum activity concentrations in oligotrophic lakes was found to be up to 0.10 m^2/kg (Fig. 5 a), implying that about 10% of the amount of ^{137}Cs deposited on one square metre is transferred into 1 kg of fish. The corresponding transfer in eutrophic lakes was clearly lower, 3-4%, at the time of maximum concentrations, which usually occurred 1-3 years after the deposition, depending on the fish species.

A relatively small uncertainty is included in the gammaspectrometric determination of ^{137}Cs in fish samples (usually less than 5%), but the uncertainty of TFs is much larger. Averages of deposited ^{137}Cs in the municipality (Arvela 1990) in that water district where the fish was caught were used. There is large variation in deposition in each municipality and the deposition into water is not necessarily the same as to soil that was measured.

Lakes and their environmental conditions vary greatly in Finland. Therefore, it is useful to develop regional transfer models. Such a model was developed and tested by VTT using the data presented here. The data in the chapter Lakes for model development was made available for the estimation of parametres. After that, background information on the other set of lakes and their catchments were given for the test of the model. The modeller then calculated ^{137}Cs in fish, and the results were compared with the ^{137}Cs values observed in fish and given here in the chapter Lakes for model validation. The model is described and the results of the validation exercise are given in the references (Suolanen 1998 and 1999).

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