

BIOGEOMONITORING OF TOXIC CHLORORGANIC COMPOUNDS IN THE ECOSYSTEM OF THE BALTIC SEA

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The study on polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAH) in the Baltic grey seal (*Halichoerus grypus*) organism was carried out in the Eastern Baltic. According to the numeration in the Estonian coastal waters during the annual molt period in May and June, size of the grey seal stock is estimated to be 1500-2000 individuals. The article is producing the reasons for the growth of grey seal stock in the Baltic Sea and brings out the concentrations of PCB in the air, water and in the food chain of a grey seal. The article also points at the impact of salinity and concentration of oxygen of the Baltic Sea on grey seal's food chain.

Key words: PCB, PAH, grey seal, food chain, salinity, the Baltic Sea.

Introduction

In 1970's, when the seal became an object of research, it was soon noticed that there was an alarming drop in their reproductive capacity. Initially it was thought to be caused by environmental toxins, primarily the insecticide DDT and the industrial chemical PCB, which were detected in high concentrations in the seals. Adult specimens of the Baltic grey seal and the ringed seal (*Phoca hispida*) suffer from a disease complex interpreted as hyper-adrenocorticism, most probably caused by organochlorine compounds and especially PCB. The disease complex includes uterine occlusions and, consequently, sterility [1].

The seals were chosen to be the subject of present research work because living at the highest level of the food chain of the Baltic ecosystem, they accumulate many kinds of highly toxic compounds [2].

The results presented by HELCOM [3] for seals from the Baltic indicate that concentrations of both, DDT and PCB, in ringed seal have decreased considerably since the early 1970's. The concentration of sDOT shows a clear decreasing tendency but there was not detected decrease in PCB concentration. Prior to the aforesaid, our attention is mainly focused on grey seal. In late 1970's, less than 2000 grey seals were registered in the Baltic Sea. Since then, the general annual population of grey seal in the Baltic has increased by 8-12%. The population of grey seal has increased in the northern part of the Baltic Proper (area in North Gotland) and in the Gulf of Bothnia. At the moment about 5300 individuals are counted in the northern Baltic as a whole [3,4].

The aim of the present study was to search reasons for the increase in grey seal population. Could it be the decreasing pollution of PCB or natural changes taking place in the Baltic Sea? Or is it the cumulative effect of the above mentioned causes?

MATERIALS AND METHODS

There are two sampling areas, the Väinameri Sea and Vilsandi National Park, are presented in Figure 1. The Väinameri Sea is the background station of chlororganic compounds in the Baltic Sea [2, 5-7]. Both areas belong to the West-Estonian Archipelago Biosphere Reserve (WEABR). The WEABR is probably the best breeding area for seals in the Baltic [8].

The method applied to analysing of grey seal samples is described in [6,9-11]. The samples were frozen immediately after collection. All the solvents used were of the highest quality available. Grey seals from Estonian coast were collected during July and October 1994 by Mr. Ivar Jässi and analysed by Dr. Anne Talvari from Estonian Marine Institute (Table 1).

The samples (10 g) were homogenized (IKA T25 homogenizer from Labasco AB, Pertille, Sweden) and extracted according to [9, 10]. Also the lipid content was determined. For the analyses of organic contaminants (PCB, PAH), approximately 0,1-0,2 g of lipids were taken. The polar lipids were separated from the sample in a silicagel (10% H₂O) and the solution was divided into two parts. For the clean-up of PAH dimethyl-formamide - H₂O and cyclohexane were used. The detailed description of the clean-up procedures used is given in [12]. The further clean-up of PCB-part was performed by two methods [9-11].

The quantitative analyses were done by gas chromatography using a mass-selective detector («Fision» 800 MS) and DB-5 capillary (30 m) column. As the internal standards in PCB analyses 13C-labelled standards served with IUPAC numbers 52, 101, 105, 118, 138, 153 and 180. By the determination of PAH, the comparison was made with a standard

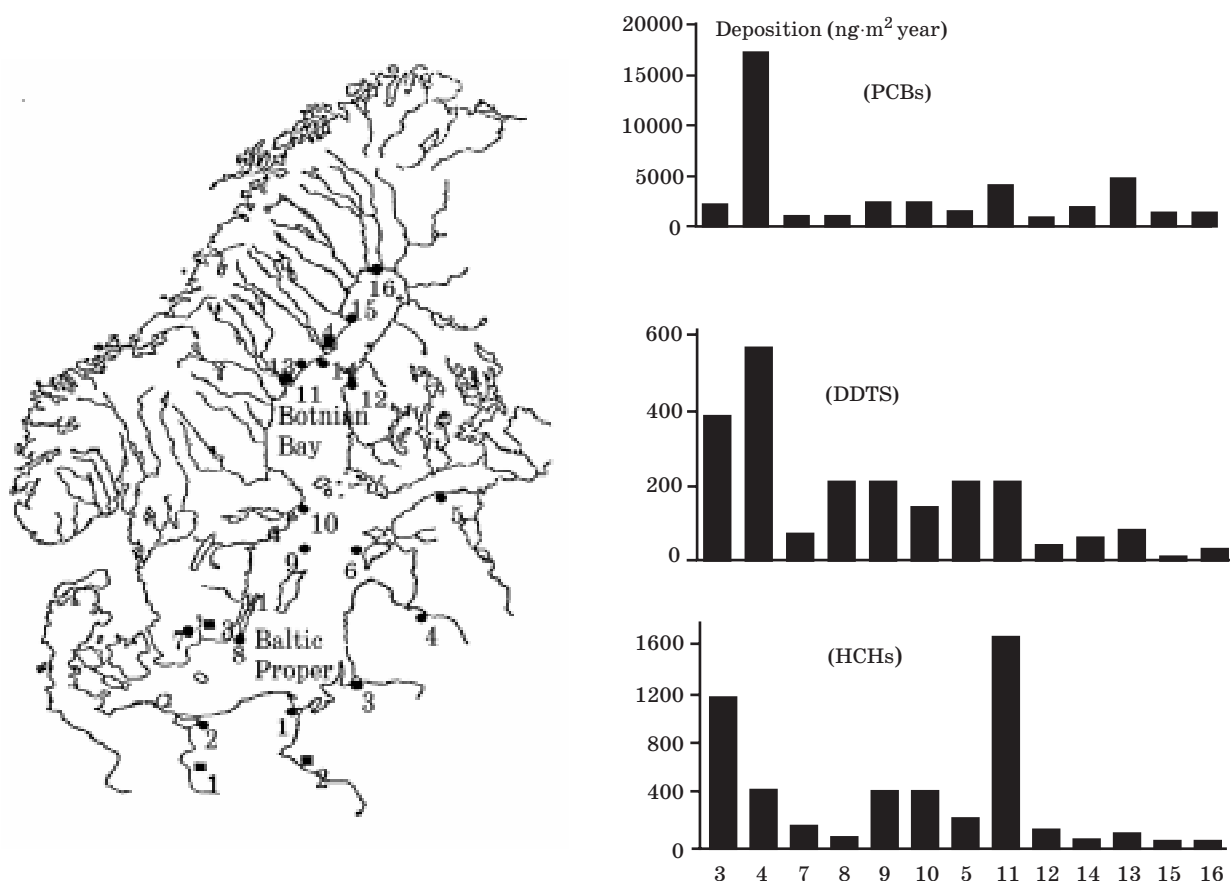


Figure 1. The sampling stations. The river sampling stations are marked by a point, and air sampling station by a triangle [7].

Рис. 1 Станции отбора проб. Станции отбора проб на реках обозначены точками, а станции отбора проб воздуха — треугольниками.

consisting of 20 PAH with 3-7 rings. As the internal standard D10 perylene was used [12].

Results and discussion

Grey seal is the largest of the seal species in the Baltic Sea region. Grey seals in large groups are mainly found in the Swedish, Finnish and Estonian Archipelago areas. A small number of grey seals are found in the Kattegat-Skagerrak area. The Estonian coastal waters serve as the south-eastern boundary of the regular distribution of grey and ringed seals in the Baltic Sea.

Comparing the PCB contents (according to Table 2) in the grey seal's blubber of Vainameri Sea and Vilsandi, appears that the PCB content in Vilsandi grey seal is higher but comparable or a bit lower than in the grey seals caught from the open Baltic Sea [1,10].

Very low fat percentage in the blubber of 6-8 year old male grey seal organism arouse interest (Table 2). By the data [1,10] only individuals with a poor nutritional status (thin layer of blubber and/or low

content of extractable fat in blubber) had significantly higher concentrations of pollutants than other groups. This is probably due to the fact that the seals had used the fat as a source of energy without being able to metabolize or excrete the pollutants at the same rate.

There is no such differences concerning PAH (Table 3).

Although there were only few samples, one can draw conclusions by saying that PCB concentrations are higher in the blubber and PAH concentrations are higher in the muscle tissue and blubber of the grey seal.

What could be the reason for such differences in PCB concentrations:

- differences of PCB inflows from an atmosphere,
- PCB inflow via rivers or
- food chain?

A grown-up grey seal eats 7 kg fish every day [13]. Changes in food chain water-plankton-fish. The seals that were fed contaminated Baltic

* See Table 1

number of samples (Table 1)

Table 1

Grey seal sampling areas and time along the Estonian coast
 Место и время отбора проб из серого тюленя вдоль Эстонского побережья

Sample	Age	Sampling	Time
		Area (Figure 1)	
1	2 – 3	Võinameri Sea -Saastna – 3	Oct. 1994
2	2 – 3	Võinameri Sea -Kiideva – 3	Oct. 1994
3	2 – 3	Võinameri Sea -Kiideva – 3	Oct. 1994
4	2 – 3	Võinameri Sea -Kiideva – 3	Oct. 1994
5	2 – 3	Võinameri Sea -Kiideva – 3	Oct. 1994
6	6 – 8	Võinameri Vilsandi National Park – 4	July. 1994
7	6 – 8	Võinameri Vilsandi National Park – 4	July. 1994
8	3 – 4	Võinameri Sea -Suursadam – 2	Sept. 1994
9	5 – 6	Võinameri Sea -Suursadam – 2	Sept. 1994
10	5 – 6	Võinameri Sea -Suursadam – 2	Sept. 1994
11	5 – 6	Võinameri Sea -Suursadam – 2	Sept. 1994
12	5 – 6	Võinameri Sea -Suursadam – 2	Sept. 1994

fish (herring) developed significantly body burdens of potentially immunotoxic organochlorines and displayed impaired immune responses as demonstrated by suppression of natural killer cell activity and specific T-cell responses. The results demonstrated that chronic exposure of environmental contaminants accumulated through the food chain affects immune function in seals, whereas short-term fasting periods do not seem to pose an additional risk [14].

- grey seal migrations [15]

- changes of salinity and oxygen concentration in the Baltic Sea.

Some other factors that we have paid attention to in our earlier works [2,6]:

direction and speed of wind and currents, amount of precipitation, amount and measurements of aerosols in the air, concentration and sedimentation rate of plankton in the water etc.

At the present time, long-range transport of PCB from southern sources outside Estonia dominate [16]. This was reflected in a decreasing south-to-north gradient of compounds in atmospheric deposition [7,17-19] and in fish [2,11,20,21].

There is no local pollution sources in the research sites, the Võinameri Sea and Vilsandi [22]. In spite of that long-range transport of air pollution still exists. Calculations of back trajectories identified different parts of Central Europe as source areas [16-19,23,24]. By Oehme et al. [19] an increased level of PCB was observed during a period of air transport from the Kola Peninsula.

By Agrell et al. [25] the deposition load of PCBs in fifteen stations around the Baltic Sea ranged from 1.2 ng m⁻² to 17.9 ng m⁻² a day (median 2.7 ng m⁻² a day). The deposition loads of PCBs in the Estonian EMEP stations, Vilsandi and Lahemaa (northern part of Estonia, 70 km to east from Tallinn) were 2.2 and 1.8 ng (m⁻² day⁻¹), correspondingly. The loads could be considered as background for the Baltic Sea. The highest deposition load of PCBs was analysed in Salaspils station near the city Riga - Latvia (Figure 1).

The Võinameri Sea is a recipient for one river - River Kasari (in 1994 the inflow of PCB into the Võinameri Sea did not exceed 0.3 kg) but there is no rivers at Vilsandi. So - studying higher PCB concentrations in grey seals at Vilsandi (comparing to the seals in the Võinameri Sea), we cannot consider big differences of PCB transport through air and river water as one of the causes. If considering all rivers discharging its water into the Baltic Sea, the PCB transport by rivers is almost at the same level as atmospheric deposition by rain - 500 kg every year [26].

There is nothing else left to suppose but the PCB concentrations obtained by food should be higher in grey seals at Vilsandi, but remaining lower than the concentrations in the 1970's [20,21,27,28].

The research on the structure of food of grey seal carried out in the beginning of 1970's mainly in the Baltic Proper showed that the food contains 23.5% of herring, 21% of cod, 12.5% of salmon, 7% of

Table 2

Concentrations (mg·kg⁻¹ extracted lipid weight) of PCB isomers in extracts of grey seal along the Estonian coast

Концентрации (экстрагированный липид/вес) РСВ изомеров экстрагированных из серого тюленя вдоль Эстонского побережья, (mg·кг⁻¹)

Sample *	Organ	Fat, %	Sex	Concentrations mg · kg ⁻¹						
				52	101	118	105	138	153	180
1	Blubber	88.2	Female	0.027	0.077	0.060	0.012	2.767	3.607	2.3
2	Muscle tissue	1.4	Male	0.088	0.153	0.093	0.027	2.828	3.917	2.2
3	Liver	2.3	Male	0.040	0.086	0.054	0.013	1.867	2.483	1.2
4	Liver	2.0	Male	0.015	0.030	0.024	0.010	0.549	0.697	0.3
5	Blubber	88.8	Male	0.040	0.150	0.080	0.030	4.105	5.152	2.3
6	Blubber	58.7	Male	0.525	0.924	0.419	0.132	25.541	44.020	23.
7	Blubber	58.7	Male	0.554	1.138	0.409	0.122	15.430	18.382	20.
8	Blubber	87.5	Male	0.046	0.102	0.078	0.023	2.288	2.878	1.5
9	Muscle tissue	5.1	Male	0.017	0.040	0.049	0.017	0.340	0.431	0.1
10	Kidney	3.7	Male	0.059	0.083	0.044	0.013	0.827	0.110	0.4
11	Live	4.7	Male	0.038	0.078	0.044	0.015	1.825	1.894	0.8
12	Blubber	91.5	Male	0.056	0.116	0.057	0.025	3.053	4.266	2.1

sea trout, 5.6% of eel and flounder, 4.9% perch and other fish in smaller amounts [13]. The food intake reaches its highest level in late autumn when seals build up blubber for winter and is the lowest in

the pupping and breeding seasons and during the molt period [13].

Also the fish species content in the Bay of Kõrde (near Vilsandi) (Figure 1) and in the Sea of Väinameri (Table 4). We found mostly thermophilic fresh-wa-

Table 3

Concentrations of ПАХ (ng·g⁻¹ of fat) in the organism of grey seal in the Estonian coastal
Концентрации ПАХ (нг·г⁻¹) в организме серого тюленя в водах Эстонского побережья

Compounds	Concentrations, ng g ⁻¹ (fat)									
	1	2	3	4	5	6,7	8	9	10	11
Fluorene	13.6	13.8	1.1	12.1	96.3	44.5	9.4	39.3	1.8	6.9
Phenanthrene	134.3	551.9	20.8	118.9	1341.6	156.3	32.6	263.7	33.9	88.6
Anthracene	22.3	61.3	2.1	11.2	246.4	9.5	6.4	15.8	0.0	18.0
3-mePhenanthrene	7.6	2484.8	2.6	20.0	60.1	38.1	7.1	62.3	6.6	9.5
1-mePhenanthrene	0.0	285.3	0.0	0.0	77.2	124.3	0.0	612.0	3.3	0.0
Fluoranthene	13.3	55.1	10.7	26.5	88.4	19.2	14.6	136.3	10.5	17.3
Pyrene	11.3	42.6	8.0	17.6	54.7	18.3	8.8	88.6	6.4	13.8
2-mePyrene	3.0	12.9	1.1	1.9	26.1	9.4	2.1	38.1	0.7	2.1
1-mePyrene	1.4	20.8	1.0	2.0	37.5	1.6	2.0	56.9	0.6	1.9
Benzo(ghi)fluoranthene	2.8	9.8	1.9	4.5	18.6	0.9	2.6	64.7	1.7	3.6
Cyclopenta(cd)pyrene	0.7	2.2	0.9	1.6	6.1	1.7	1.5	11.2	0.3	1.0
Benzo(a)anthracene	1.7	6.9	1.8	3.6	23.6	6.7	2.8	43.2	1.3	2.6
Chrysene	9.8	37.7	7.8	16.7	64.2	17.2	8.0	314.4	8.2	14.5
Benzo(k)fluoranthene	2.4	10.1	2.3	6.8	30.6	1.9	3.1	45.9	1.9	3.5
Benzo(e)pyrene	3.4	21.5	3.9	9.7	59.0	4.2	3.3	9.0	3.0	5.7
Benzo(a)pyrene	6.1	4.6	1.7	2.4	17.5	0.8	4.1	4.5	0.4	1.4
Perylene	0.0	20.5	2.5	3.8	92.6	8.7	13.3	5.1	0.5	1.2
Indeno(1,2,3-cd)pyrene	2.9	29.0	4.6	13.8	97.1	2.6	3.6	52.4	3.1	4.2
Benzo(ghi)perylene	0.0	62.3	9.9	9.1	67.1	12.7	13.9	60.2	10.8	9.7
Coronene	3.7	30.5	2.1	7.1	16.8	2.0	2.6	37.5	2.1	3.0
Σ ПАХ	239.4	3768.8	86.2	289.3	2500.5	480.6	141.8	1961.1	97.1	208.5

Table 4

Indices of the experimental catches in the monitoring sites of Hiiumaa islets (Vainameri) and the Bay of K-dema. Species which percentage of catches exceeded 2.0 [29].

Показатели экспериментальных уловов в контрольных участках у островков Hiiumaa (V S inameri) и Залива K - dema. Разновидность рыб, процент которых от улова превышает 2.0 [29].

Species	Catches (%)	Mean stature (cm) , (L, cm)
Hiiumaa islets		
Roach	47	16.2
Perch	36	20.2
Baltic herring	8.5	17.6
Ruff	4.2	13.5
Bay of K-dema		
Baltic herring	59.1	23.2
Flounder	28.8	18.6
Cod	7.7	35.3

ter fish in the shelf of the Vainameri Sea and quite a lot frostphilic marine fish in the Bay of K-dema. The content of fish species in these two areas has remained stable in last 4-5 years, the number of main species has not changed very much, too [29].

If comparing Table 4 and control catches carried out in 1976-1978 and 1988-1990 [30], one can notice the share of cod has decreased considerably. The average number of cod caught in one hour of experimental trawling depth zones (5-40 m) in the Gulf of Riga in the summers of 1976-1978 was 380 fish and in the summers of 1988-1990 it was 1 fish in one hour.

Thus, the food chain of grey seal has changed leaving an essential part out (in Vainameri) or reducing it (in the open sea at Vilsandi). According to Table 4, the number of fat fish (salmon, sea trout etc.) is small in these areas. The control catches in different years also consisted of some sea trouts in the Bay of K-dema [29].

Cod is suitable indicator for examining water pollution by bioaccumulative organochlorines because of its higher ranking predation in the food chain and reasonably sedentary life style. Cod liver is rich in fat (50-85%) and hence used as a raw material in the production of cod-liver oil. Most of the organochlorines, except sDOT in cod-liver oil from the southern Baltic Proper (1971-1989) tended to decline at a very slow rate and in some cases a steady state was observed [27,31]. Since 1982, the use of Baltic cod-liver oil for medical purposes in Poland has been restricted due to higher organochlorine contamination. They exceed the tolerance limit of total PCB's (2.0 ug g⁻¹ for edible parts of fishery products) and contain significant residue levels of toxic coplanar PCB [27,31].

Another important food for grey seal is the Baltic salmon. Salmon is a pelagic feeder and prey main-

ly on herring in the open Baltic Sea. The few analyses performed on the Baltic salmon [32,33] indicate levels of persistent pollutants at least two orders of magnitude than for cod that contains little amount of fat. A high fat content is often correlated with long spawning or foraging migrations in which the fat is used for gonadal growth or as an energy source [33]. Large proportion of salmon in the Baltic Sea originates from compensatory hatcheries, where adult fish are caught in the river and used for breeding. During 1992, the mortality of fry was 45-90% in different hatcheries. The high mortality of fry originates from individual females, where all the fry die [33]. Persistent pollutants were indicated to as the cause of mortality. High mortality rate of salmon fry was recorded at a PCB concentration of 9 ppm [32].

As a result, the cod and salmon caught from the southern part of the Baltic Sea may be dangerous for grey seals to eat, and also Baltic herring [34].

At present, the concentration of PCB keeps flowing to the sea by rivers. The investigations have been carried out there on the pollution caused by organic substances in the cross-section near the mouth of River Vistula, the longest river in Poland and a second to one estuary of the Baltic Sea. Summary DDT and PCB loads floated down the Vistula River in 1983 were 580 kg and 206 kg, in 1984 - 450 kg and 190 kg, respectively [35]. During 1991-1992, Johansson [26] studied the transport of PCBs into the Baltic Sea via River Vistula (1991 - 14.5 kg and 1992 - 17.3 kg) and River Oder (1991 - 9.4 kg and 1992 - 15.4 kg). Consequently, the pollution of PCB in the southern part of the Baltic Sea is continuing.

Hereafter we pay attention to the grey seals at Vilsandi because the grey seal in Vainameri probably feeds on Baltic herring, perch etc. Chloroorganic

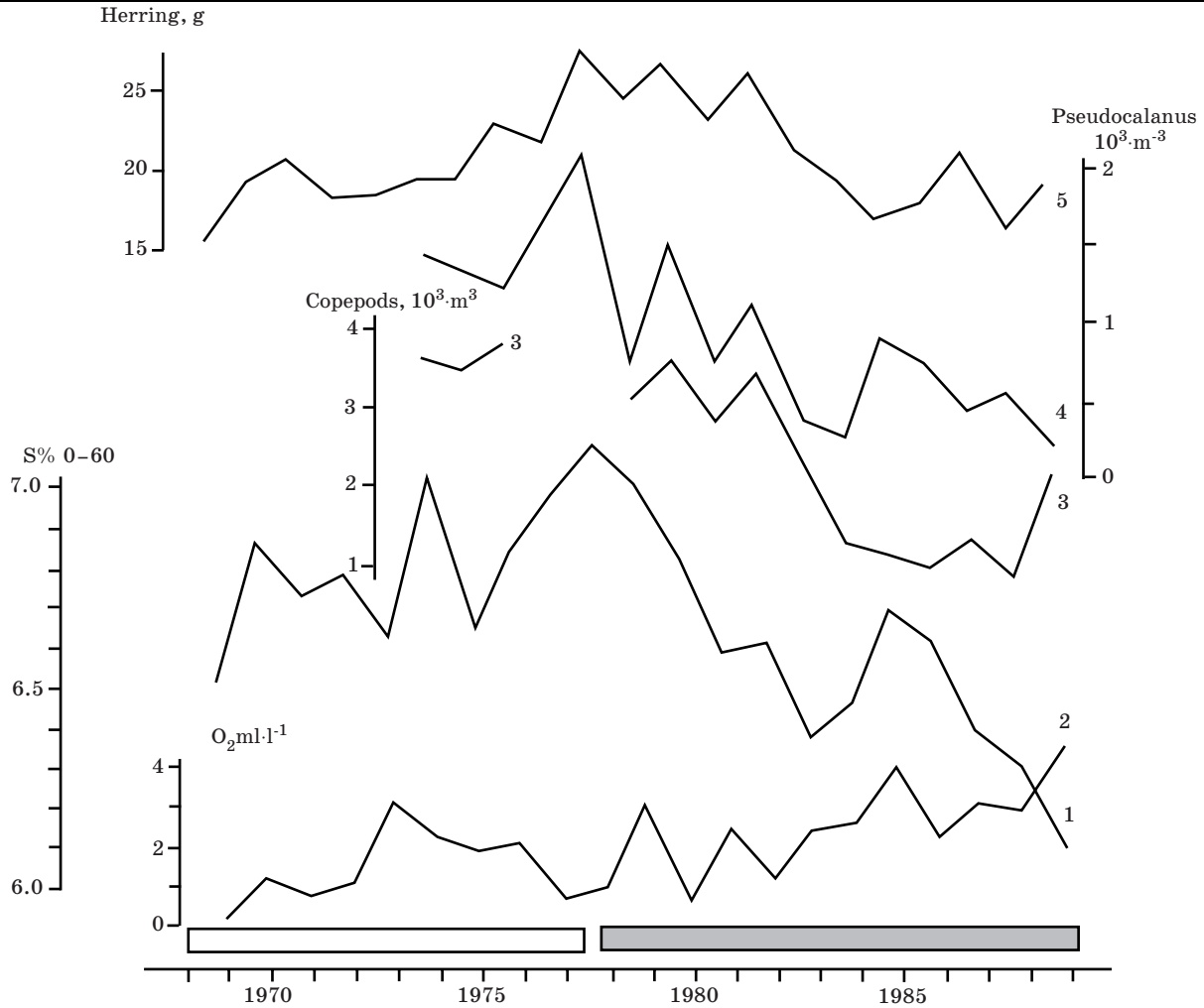


Figure 2. Relationship between the average water salinity, oxygen content, copepod abundance, and the average weight of the 2-year-old herring in the Gulf of Finland in 1969-1989. 1— salinity of the 0–60 m layer; 2 — oxygen content of the 70–90 m layer; 3 — average copepod abundance in May; 4 — average abundance of *Pseudocalanus elongatus* in August; 5 — average weight of the 2-year-old herrings; periods of 1 — low, and 2 — high river discharge [40].

Рис 4. Отношения между средней соленостью воды, содержанием кислорода, сорерод изобилие, и средний вес 2-летней сельди в Заливе Финляндии в 1969-1989. 1 — соленость из 0-60 м. слой; 2 — содержание кислорода из 70-90 м. слой; 3 — составляют в среднем сорерод изобилие в мае; 4 — составляют в среднем изобилие *Pseudocalanus elongatus* в августе; 5 — составляют в среднем вес 2-летних сельдей; периоды 1 — низко, и 2 — высокая речная разгрузка [40].

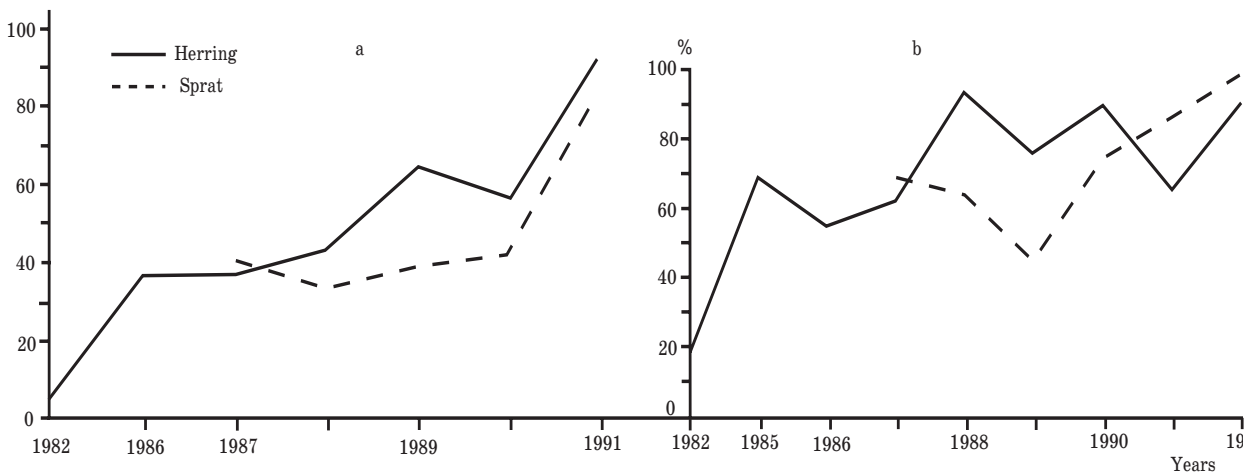


Figure 3. Proportion of herring and sprat with empty stomachs in the northern Baltic in April 1982–91 (a) and in November–December 1982–92 (b) [41].

Рис 3. Отношение сельди и кильки с пустыми животами в северном Балтийский в апреле 1982-91 (a) и в ноябре - декабре 1982-92 (b) [41].

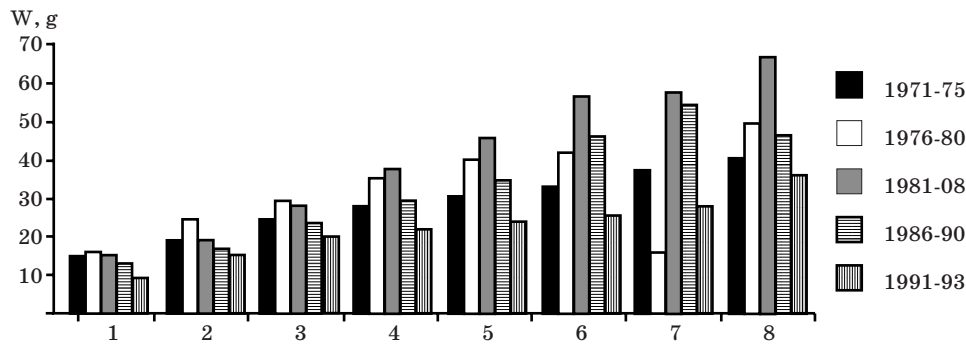


Figure 4. Mean weight differentages of herring in the Gulf of Finland in 1997–93 [41]
Рис 4. Средний вес различных видов сельди в Финском заливе в 1997–93 годах. [41].

content in these is one of the lowest in the Baltic Sea [2,5,6].

Comparing the food chain of grey seal in the open sea in the beginning of 1970's [13] and species content during examination catches in spring 1995 (Table 4), we can assume that nowadays the grey seals, caught from Vilsandi monitoring site, cannot have so much cod, salmon and sea trout than in the end of 1970's and in the beginning and in the middle of 1980's.

Cod plays a rather important role in the Estonian fishery during the periods of high salinity in the Baltic Sea, while the catches of cod (20 000 t) peaked in the early 1980's. Currently, the cod is not being fished in the economic zone of Estonia [36].

The inflow of brackish oxygen rich water from the North Sea during the winter of 1993-1994 might have caused cod to move northwards. At the time, salinity in the Gotland Deep rose to 12.5 psu. First time after 1955, the oxygen concentration in the Gotland Deep exceeded 3 ml L-1. By 1995 it had dropped to 1 ml L-1 [37].

Only the strongest of major inflows can renew the deep water of the Eastern Gotland Basin.

New research indicates that the level of salinity is also of major importance for cod reproduction, and that M74 syndrome could possibly also affect cod, salmon and sea trout.

Swedish scientists at the Stockholm University have demonstrated in experiments that the Baltic cod needs a salinity of 13-15 per mille, instead of 10-11 per mille as previously claimed. The salinity requirement may also vary between different female cod-older females seem to tolerate a lower salinity. Scientists have also demonstrated that in order to survive, the newly hatched cod larvae require oxygen concentrations of 2 ml L-1 of sea water, which is twice as much as has been assumed [38].

In stagnation periods, the emigration rate of cod from the northern part of its distribution area to the southern and south-western spawning grounds was the highest [39]. As the southern Baltic is far away from the Gulf of Riga, only a very limited number of young and also adult cod finds its way into the Gulf of Riga.

It can be assumed that the Gotland Deep has changed into a natural-neutral zone. Cod reproduces in the south (Bornholm Bay) but cannot spawn in the Gotland Deep which has low salinity and low oxygen concentration. Also an adult seal would not go to the Gotland Deep because there is neither cod nor suitable lying ground. Low salinity and oxygen concentration has become to affect the evolution of grey seal's (also cod's and salmon's) main food - Baltic herring and sprat.

The mean weight of herring has been decreasing not only in the Gulf of Finland [40,41] but almost in all regions of the Baltic Sea [36]. Growth processes depend largely on feeding. The share of starving fish and the prey composition reflect the feeding conditions for herring. Lumberg et al., [40] analysed the dynamics of zooplankton abundance and biomass in the Gulf of Finland during the last 30 years. The decreased salinity has caused both, changes in the species composition of zooplankton and a decrease in its abundance. Young herring lives mainly on zooplankton and its average weight is in significant correlation with the copepod abundance in the growth period $R = 0.61$; $P 0.05$ (Figure 2). It can be supposed that after 1982 herring had to utilise food organisms of generally poorer quality than during the five year period before [40].

The studies concerning the feeding of herring and sprat that were carried out during the years 1982-1992 in north-eastern part of the Baltic Sea showed changes in the diet of the fish and also the rising number of fish with an empty stomach (Figure 3). The average body weight of herring, which had been relatively stable during 1940-1960, started to increase in most regions of the Baltic Sea in the late 1970's. High average values of body weight and length were observed in all age groups of herring until the second half of the 1980's, when they started to fall unexpectedly. In the 1990's, also a drop in the average body weight of sprat occurred (Figure 4) [41]. Hydrological conditions are at least partially responsible for the rapid deceleration in the growth of sprat and (especially) herring [2,40,41].

Increase in the percentage rate of empty stomachs of Baltic herring and sprat in the beginning of

1990's may turn out to be one of the reasons for the decrease of PCB concentration in food, comparing with the end of 1970's and the beginning of 1980's.

Author [2,42] recommends that besides herring's age, length, weight, sex, fat percentage and degree of maturity, in the future the percentage of empty stomachs (and the content of different food in stomach) should be considered as an additional parameter [2]. One can assume that the rising number of fish with an empty stomach has contributed to the stability of chloroorganic compounds contents in herring organisms in the northern part of the Baltic Sea [2,42].

Besides the above mentioned, the PCB concentrations in grey seals may also depend on migrations. There is quite little information about grey seal's present migrations [15]. Recovery of tagged seals indicated that at least pups leave whelping areas and disperse. Probably most of such pups found on the shore or in fishing gears have been moving to the south [15]. Seals born in the northern part of the Gulf of Riga were found mainly in t

Especially dangerous is the migration of grey seals, younger than one year, to the southern part of the sea. The female grey seal's milk contains 60-80% of fat and a large amount of lipid soluble contaminants are passed from mother to pup [44]. In the southern part of the sea, the food has higher PCB concentrations than in the northern part.

Grey seals in the Gulf of Bothnia and the Baltic Proper give birth to their pup in February-March. By Hongell [45], the chromosome aberrations are probably caused by chemical pollutants. Blood samples were taken from 47 grey seal pups before weaning in March-April and from ten adult ringed seals in the end of April during 1988-1992. The types of aberrations found were chromosome and chromatid breaks, gaps and fragmentations. More complicated rearrangements were rare. The frequency of aberrations found in the adult Baltic ringed seals were lower than those found in the grey seal pups. The mean frequency of cells with chromosome aberrations from grey seals was 5.7% (SD + 5.3), but some individuals have a considerably higher frequency of aberrations than the average. Some cells with several aberrations and fragmentation of the chromo-

somes were observed among the lymphocytes from these animals [45]. It is necessary to continue studying the migrations along with food-chain. Research objects were male individuals as part of PCB concentrations in females is carried out from their body during the feeding period of the young ones. Female grey seals with high PCB concentrations do not only harm their offsprings. By some data [46], they may not only feed their own pups, which makes studies more complicated. One of the most important indices of PCB concentrations is annual amount of precipitation. For instance, precipitation may influence the PCB concentrations in the Baltic Sea ecosystem during the following year [2], since the transition of PCB components from organisms, the so-called clearance half-lives vary from ten days for 2,5-dichlorophenyl, sixty days for 2,3',4',5-tetrachlorobiphenyl, which is correlated with the decreasing aqueous solubilities of the compounds [47]. One may assume that the clearance half-lives of penta-, hexa- and heptachlorobiphenyls are considerably higher. The potential dependence of PCB concentration in the cod liver upon the amount of the previous year precipitation is shown in our earlier studies [2,48].

As a result, we have to pay more attention to the salinity and oxygen concentration in sea water, the annual amount of precipitation and its PCB concentrations. Tightening the cooperation between the Baltic Sea countries is necessary. First successful steps in this field were made in the beginning of 1990's already [7,25,33].

Conclusion

Over the past decades increased knowledge of the behaviour of pollutants in the aquatic environment and their effect on the ecosystem, as well as a tendency towards a more cost effective strategy for monitoring, has led to a growing interest in additional monitoring approaches. The integration of chemical and biological monitoring provides more comprehensive information on quality assessment and ecological functioning of aquatic ecosystems [2,27,31].

Comparing to the end of 1970's and the beginning of 1980's, at least the PCB concentrations ob-

References

1. Roos A., Blomkvist G., Jensen S., Olsson M., Bergman A. and Harkonen T. (1992) Sample selection and preparation procedures for analyses of metals and organohalogen compounds in Swedish seals. *AMBIO*. **21**, 525-528.
2. Roots O. (1996) Toxic Chloroorganic compounds in the Ecosystem of the Baltic Sea. Ministry of the Environment of Estonia, Environment Information Centre, pp.1-144.
3. HELCOM (1996) Baltic Sea Environment Proceedings. Activities of the Commission 1995. **62**, 1-115.
4. WWF Baltic Bulletin (1995) Cautious optimism — but seals not yet out of danger. **1**, 4-14.
5. Blomkvist, G., Jensen S and Olsson M (1993) Concentrations of organochlorines in perch (*Perca fluviatilis*) sampled in coastal areas of the Baltic Republics. Report Swedish Museum of Natural History, 10.09.1993, p.p 1-11 (mimeogr.).
6. Roots O (1995) Organochlorine pesticides and polychlorinated biphenyls in the ecosystem of the Baltic Sea. *Chemosphere* **31**, 4085-4097.

7. Larsson P., Jørnmark C., Bremle G., Backe C and Okla L. (1995). Storskaliga processer och milj-effekter i -stersjn. Information fr?n forskningsavdelningen. Nr. 3, 15–17.
8. The Estonian Fund for Nature (1992) Tallinn, 30p.
9. Jensen S., Reuthergardh L. and Jansson B. (1983) Analytical methods for measuring organochlorines and methyl mercury by gas chromatography. Analysis of metals and organochlorines in fish. FAO Fish Tech. Paper, Rome, 212, 21-33.
10. Haraguchi K., Athanasiadou M., Bergman, M., Hovander L. and Jensen S. (1992) PCB and PCB Methyl Sulfoxones in Selected Groups of Seals from Swedish Waters. *AMBIO*. 21, 546–549.
11. Roots, O. and Aps R. (1993). Polychlorinated biphenyls and organochlorine pesticides in the Baltic herring and sprat. *Tox. and Environ. Chem.* 37, 195-205.
12. Broman D., Naf C. and Zeb-hr Y. (19) Long-term high and low-volume air sampling of polychlorinated dibenzo-p-dioxins and dibenzofurans and polycyclic aromatic hydrocarbons along a transect from urban to remote areas on the swedish baltic coast. *Environ. Sci.Technol.* 25, 1841-1850.
13. S derberg, S. (1975) Feeding habits and commercial damage of seals in the Baltic. In: Proc. Symp. on the Seal in the Baltic. Solna. SNVPM 591, pp. 66–78.
14. Swart De., Ross P.S., Vos J.G. and Osterhaus A.P. (1996). Impaired immunity in harbour seals (*Phoca vitulina*) exposed to bioaccumulated environmental contaminants. review of a long-term feeding study. *Env. Health Perspectives.* 104, 823–828.
15. Helle, E. and O. Stenman. (1991). Itämeren hyljekannat, 1986–1990. WWF No. 1. Helsinki; 76p.
16. Roots O., Saar J. and Saare L. (1992) Air quality above the territory of Estonia. In: Air Pollution in Estonia 1985–1990. Helsinki. Environmental Report 3, pp. 5–28.
17. Bouchertall F. (1988) Atmospheric transport of PCB to the Baltic Sea. Fifth Meeting of the Group of Experts on Airborne Pollution of the Baltic Sea Area. Gdynia. EGAP 5/INF. 7, pp. 1–7.
18. Larsson P. and Okla L. (1989) Atmospheric transport of chlorinated hydrocarbons to Sweden in 1985 compared to 1973. *Atmos. Environ.* 23, 1699–1711.
19. Oehme, M., Haugen J.E. and Schlabach M. (1995) Ambient air levels of persistent organochlorines in spring (1992) at Spitsbergen and the Norwegian mainland, comparison with 1984 results and quality control measures. *The Sci. of the Total Environment.* 160/161, 139–152.
20. Roots, O. and Peikre E. (1978) PCB and chlororganic pesticides in the Baltic herring. *Proc. Estonian Acad. Sci. Chemistry*, 27, 193–196.
21. Jensen, S., Johnels A. and Olsson A. (1969) DDT and PCB in Swedish waters. *Nature.* 224, 247–250.
22. Roots, O. (1996). The state of atmospheric emissions and the air quality. Main stationary and mobile air pollutants. Estonian Environment. Past, Present and Future. (Ed. by A. Raukas). Ministry of the Environment of Estonia. Environment Information Centre. Tallinn. 123–127.
23. Eriksson, G., Jensen S., Kylin S. and Strachan W. (1989) The pine needle as a monitor of atmospheric pollution. *Nature.* 341, 42–44.
24. Calamari D., TremoladaP., Guardo A.D. and Vighi M. (1994). Chlorinated hydrocarbons in pine needles in Europe, Fingerprint for the past and recent use. *Environ. Sci. Technol.* 28, 429–434.
25. Agrell C., Larsson P., Okla L., Bremle G., Johansson N. and Zelechowska A. (1997). Atmospheric and Riverine Input of Hydrophobic, Chlorinated Organic Pollutants to the Baltic Sea. Submitted to Large Scale Effects in the Baltic Sea (Eds. Wulff, F., Rahm, L. and Larsson, P.). Springer Verlag. Germany.
26. Johansson, N. (1994) River transport of PCBs to the Baltic Sea. Chemical Ecology and Ecotoxicology, Department of Ecology, Lund University. 1–16.
27. Falandysz, J., Tanabe S. and TatsukawaR. (1994) Most toxic and highly bioaccumulative PCB congeners in cod-liver oil of Baltic origin processed in Poland during the 1970's and 1980's, their TEQ-values and possible intake. *Science of the Total Environment* 145, 207–212.
28. HELCOM. (1990) Baltic Sea Environment Proceedings. Background Document. Second Periodic Assessment of the State of the Marine Environment of the Baltic Sea, 1984–1988. 35B, pp. 371–432.
29. Kangur M. (1996). Mereelustiku seire. Keskkonnaseire (1995) (Toim. O. Roots ja R. Talkop), Keskkonnaministeeriumi Info- ja Tehnokeskus, pp. 83-85.
30. Ojaveer, E. and Gaumja R. (1995). Cyclostmes, fishes and fisheries. Ecosystem of the Gulf of Riga Between 1920 and 1990. *Estonian Academy Publishers. Academia* 5, 212–268.
31. Kannan, K., Falandysz I., Yamashita N., Tanabe S. and Tatsukawa R. (1992). Temporal Trends of Organochlorine in cod-liver oil from the southern Baltic Proper, 1971–1989. *Marine Polluti. Bull.* 24, 358–363.
32. Norrgren, Andersson L. T., Bergqvist P.A. and Bj rklund I. (1993). Chemical, physiological and morphological studies of feral Baltic salmon (*Salmo salar*) suffering from abnormal fry mortality. *Environ. Toxicol. Chem.* 12, 2065–2075.
33. Larsson P., Backe C, Bremle G., Ekl v A. and Okla L. (1996). Persistent pollutants in a salmon population (*Salmo salar*) of the southern Baltic Sea. *Can. J. Fish. Aquato Sci.* 53, 62–69.
34. Falandysz, J. (1984) Organochlorine pesticides and PCB in herring from the southern Baltic, 1981. *Z. Lebesm. Unters. Forsch.*, 179, 20–23.
35. Niemirycz E., Korzee L. and Makowski Z. (1988) Outflow of same organic substances transported by the Vistula River into the Baltic Sea. In: Proc. XVI Conf. of the Baltic Oceanographers. Kiel. 2, pp. 760–776.
36. Raid T. (1996). Main commercial sea fish stocks. Estonian Environment. Past, Present and Future. (Ed. by A. Raukas) Ministry of the Environment of Estonia. Environment information Centre. Tallinn. 78–82.
37. Annual Report (1995). (1996). Finnish Institute of Marine Research, pp. 1–16.
38. WWF Baltic Bulletin. (1995). Baltic fish at risk. 4–5, 5–10.
39. Aro E. and Sjöblom Z. (1983) Cod off the coast of Finland in 1974–1982. *ICES C.M. I.* 26, pp. 1–12.
40. Lumberg, A. and Ojaveer E. (1991). On the environment and zooplankton dynamics in the Gulf of Finland in 1961–1990. *Proc. Estonian Acad. Sci. ecol.* 1, 131–140.
41. Raid T. and Lankov A. (1995). Recent changes in the growth and feeding of Baltic herring and sprat in the north-eastern Baltic Sea. *Proc. Estonian Acad. Sci. Ecol.* 5, 38–
42. Roots, O. (1996). PCB and chlororganic pesticides. Assessment of health risk associated with the consumption of seafood. *Proc. Estonian Acad. Sci. Ecol.* 6, 124–135.
43. Pilats, V. (1995). Seals in Latvia, residents or visitors? *The Lithuanian Acad. Sci. Ecol.* 2, 86–89.
44. Blomkvist C., Roos A., Jensen S., Bignert A. and Olsson M. (1992). Concentration of sDDT and PCB in seals from Swedish and Scottish waters. *AMBIO.* 21, 539–545.
45. Hongell, K. (1996). Chromosome survey of seals in the Baltic Sea 1988–1992. *Archives of Env. Contamination and Toxicology.* 31, 399–403.

46. Pomeroy, P.P., Green N., Hall A.J., Walton M., Jones K. and Harwood J. (1996). Congener — specific exposure of grey seal (*Halichoerus grypus*) pups to chlorinated biphenyls during lactation. *Can. J. Fish. Aquat. Sci.* **53**, 1526–1534.
47. Br-ggemann W.A., Marton L.B, Koolman D. and Hutzinger O. (1981) Accumulation and elimination kinetics of di-, tri- and tetrachlorobiphenyls by goldfish after dietary and aqueous exposure. *Chemosphere*. **10**, 811–832.
48. Roots, O. (1991). PCB and their components in the Baltic Sea. *Proc. Estonian Acad. Sci. Chem.* **39**, 9–17.

**Биомониторинг токсических хлорорганических веществ
в экосистеме Балтийского моря**

Ott Roots

Было изучено наличие полихлорированных бифенилов (PCB) и полициклических ароматических углеводородов (ПАУ) в организмах балтийских серых тюленей (*Halichoerus grypus*) в восточной части Балтийского моря. Согласно подсчету в течение ежегодного периода линьки в мае и июне в Эстонских прибрежных водах популяция Серого тюленя составляет примерно 1500–2000 особей. Показаны причины роста популяции Серых тюленей в Балтийском море и прослежено продвижение PCB по цепочке воздух–вода–пища–Серый тюлень. Выявлено воздействие солености воды и концентрации кислорода в воде Балтийского моря на пищевую цепочку Серого тюленя