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REPRODUCTIVE TRENDS AND OCCURRENCE OF ORGANOCHLORINES AND HEAVY METALS IN THE BALTIC SEAL POPULATIONS

by

Eero Helle

Department of Biology, University of Joensuu,
P.O. Box 111, 80101 Joensuu 10,
Finland

SUMMARY

The levels of PCBs, total DDT, mercury, selenium, cadmium, zinc and chromium in the Baltic seal populations in 1974-79 are studied in relation to age, sex and reproductive status of the female.

The productivity of the Baltic seal stocks decreased sharply during the 1970s, e.g. the proportion of all sexually mature females which reproduced normally dropped to less than 25 % in the ringed seal (Phoca hispida) population in the Gulf of Bothnia. This was due to an increasing number of occlusions of the uterine tract. This pathological change is also known in the grey seal (Halichoerus grypus) and the harbour seal (Phoca vitulina).

Both PCBs and total DDT levels in ringed seals in the Gulf of Bothnia reached their maximum in 1977. No statistical differences in levels were found between the sexes or the reproductive categories of females in 1977-78 although these had occurred in 1974-75. Total Hg and Se levels in the liver (mean 51 and 16 ppm) were higher in the females than in the males. Levels of Cd, Zn and Cr in the ringed seal liver averaged 0.77, 30.8 and 0.56 ppm respectively, with no differences between the sexes or reproductive categories.

A positive correlation emerged between PCBs and total DDT (r=0.788), Hg and Se (r=0.956) and Cd and Zn (r=0.515), and an indicative one between Cd and Hg, and thus also between Cd and Se. Indicative negative correlations emerged between DDT and both Hg and Se. Zn was the only component which correlated with the age of the seal (r=-0.433) in 1977-78.

The present results show that the relationship between high levels of environmental toxins and reproductive failures in seal populations is highly complex and that organochlorines and heavy metals may have combined effects. Attempts to resolve the causes of the reproductive failures experienced in the Baltic are also hampered at present because of the continuous changes in levels of environmental toxins.

RÉSUMÉ

Les niveaux des PCB, le total des DDT, mercure, selenium, cadmium, zinc et chrome chez la population des phoques dans la mer Baltique ont été étudiés durant les années entre 1974 et 1979 en relation de l'age, du sèxe et du status reproductif de la femelle.

La reproduction des phoques dans la Baltique a fortement diminué durant la décennie de 1970, par example la proportion de toutes femelles qui ont atteint leur maturité sexuelle se reproduisant normallement, est tombé à moins de 25 % chez les phoques annelés (Phoca hispida) dans le Golfe de Bothnie. Ceci a été du a une augmentation des occlutions de l'utérus. Ce changement pathologique est aussi connu chez les phoques gris (Halichoerus grypus) et les phoques veau-marins (Phoca vitulina).

Les niveaux de PCB comme le total des DDT a atteind chez les phoques dans le Golf de Bothnie leur maximum en 1977. Aucune différence statistique a été trouvé dans les niveaux entre les sexes, ou les catégories reproductives des femelles en 1977-1978 comme cela c'était passé en 1974-1975. Les niveaux du total de Hg et le Se dans le foie (en moyenne 51 et 16 ppm) étaient plus élevés chez les femelles que chez les mâles. Les niveaux de Cd, Zn et Cr dans le foie du phoque annelé qu'on a trouvé étaient en moyenne de 0.77, 30.8 et 0.56 ppm respectivement, sans aucune différence entre les sexes ou les catégories reproductives.

Une correlation positive est apparue entre les PCB et le total des DDT (r=0.788), le Hg et Se (r=0.956), le Cd et Zn (r=0.515) et une correlation indicative entre le Cd et Hg, donc aussi entre le Cd et Se. Des correlations indicative négative sont apparues entre le DDT et les deux Hg et Se. Le Zn était le seul composant que l'on pouvait faire correspondre avec l'age du phoque (r=-0.433) en 1977-1978.

Les résultats actuels montrent que le rapport entre le haut niveau de toxines dans l'environnement et les échecs de la reproduction parmis la population des phoques est hautement complex et que l'organochlorine et les métaux lourds peuvent avoir des effets continués. Les tentatives pour résoudre les causes des échecs de la reproduction expérimenté dans la Baltique sont aussi interrompue pour le moment à cause des changements continuels du niveau des toxines dans l'environnement.

INTRODUCTION

The Baltic Sea is inhabited by three species of seal, the ringed seal (Phoca hispida), the grey seal (Halichoerus grypus) and the harbour seal (Phoca vitulina), and the numbers have been recently estimated to around 10,000, 2-5,000 and 200 respectively. The Baltic seal populations have decreased markedly during the last 2-3 decades (e.g. Hook & Johnels, 1972; Söderberg, 1975), firstly due to excessive hunting and since the late 1960s due to lowered reproductive capacity (e.g. Helle, 1980a). In the mid-1970s a correlation was found between high levels of both PCBs and total DDT and the occurrence of reproductive failures, and partly on the basis of laboratory experiments it was proposed that PCBs in particular may have intefered with reproduction (Helle et al., 1976a, Olsson, 1977). Although the great importance of heavy metals in the metabolism of marine mammals is commonly known, only a few notes have been published on their occurrence in the Baltic seal populations, and none which deal with different reproductive categories in the female seals.

The purpose of this paper is to review organochlorine levels (PCBs and total DDT) in the Baltic seal populations, to present results on heavy metal analyses and to study in more detail the co-occurrence of these components in a ringed seal population suffering from frequent reproductive failures.

MATERIAL AND METHODS

Results on reproductivity and organochlorine analyses have already been published or they are just under publishing, and thus the materials and methods have been described in the proper contexts. PCB and DDT levels are expressed in mg/kg of extractable fat from the blubber.

Twenty-two liver samples from the ringed seal population in the Gulf of Bothnia (see Fig. 1), collected in 1977-78, were analyzed for total mercury, selenium, cadmium, zinc and chromium. The material consists of 5 normal pregnant females, 12 females with uterine occlusions and 5 males, the mean age being 14.4, 17.5 and 17.6 years respectively. It is worth mentioning that all results, the reproductive condition and levels of both organochlorines and heavy metals, are based on shot or seal netted specimens (see Helle, 1980a), in contrast to several other studies, which are based on specimens found dead. Heavy metals were analyzed by atomic absorption techniques, Zn by the flame method, Cd and Cr by the flameless method, Se by the sodium-borohydride method and total Hg by the cool vapour method (for more detail on the procedures, see Saari & Paaso, 1980).

REPRODUCTIVE CAPACITY

The most exact and almost the only studies on reproduction in the Baltic seals deal with the ringed seal population in the northern Gulf of Bothnia (see Fig. 1). The first scientific note, from the years of 1972-73, shows that only 30 % of the mature females were pregnant in October-November (Helle, 1975). The reproductive capacity decreased further after that, so that only 20 % were pregnant in 1979 (Helle, 1980b). It has been possible to evaluate retrospectively the onset of the lowering trend which took place in the late 1960s (Helle, 1981).

This uniquely low level of reproductivity has been due to (1) disturbances in foetal development, leading to the formation of pathological uterine occlusions, and (2) females with normal ovulation (=bearing a corpus luteum) but without any foetus (Helle, 1980b). The latter group, averaging 23 % of the mature females in 1974-79, is also a category of reproductive failure, but it is not known at present whether it is a natural phenomenon in the present ringed seal population (cf. e.g. Nazarenko & Beloborodov, 1974). It is worth mentioning that the ovulation frequency reached 0.984 in the population in question (Helle, 1980b).

The pathological uterine occlusions, usually occurring as thin membranes of connective tissue, are the most dangerous factor threatening the populations. These increased in frequency from 34 % in 1974-75 to 59 % in 1977-79 (Helle, 1980b). If an occlusion already existed in one of the uterine horns, one of the following pregnancies in the opposite horn usually ended in the blocking of that horn, too. The proportion of females with an occlusion in both uterine horns within all occluded females had reached approx. 40 % by 1977-79. The frequency of this uterine occlusion correlated positively with the age of the seal (Helle, 1980b).

No corresponding material on reproduction is available from anywhere else in the Baltic area, but there are some hints that a considerable number - even a half - of the grey seals in the Baltic proper are suffering from the same disturbance, and occlusions have also been met with in harbour seals in the Straits of Denmark (Helle et al., 1976a). Thus it seems most probable that the uterine occlusion is prevalent throughout the Baltic Sea, but the frequency is known exactly only in the ringed seal population of the Gulf of Bothnia.

RESULTS

Organochlorines

The mean levels of PCBs and total DDT in the ringed seal population of the Gulf of Bothnia in 1972-80 are given in Table 1. DDT remained at about the same level from 1972 to 1977, but that of PCBs increased up to 1977, since when the levels of both compounds have decreased markedly. The maximum figures were 100 ppm for PCB and 310 ppm for DDT in 1973-75, 389 and 357 ppm in 1977, and only 190 and 71 ppm in 1979-80, respectively (Karppanen & Henriksson, 1974; Helle et al., 1981).

The levels of PCB and DDT were 2-4 times higher in both ringed and grey seals in the Gulf of Finland and the Baltic proper in 1969-74 (Karppanen & Henriksson, 1974; Helle et al., 1976a), but no more recent results are available.

The distribution of PCBs and DDT by sex and the reproductive performance of the female is described in Table 2. It was noticed in 1975 that females with pathological uterine findings had higher levels of both PCB and DDT than normal pregnant females (Helle et al., 1976a). The same may also hold true in 1978-80, but the material is not large enough to give statistical support for this. The most fundamental change between the two samples in Table 2 seems to be the steep drop in levels of DDT in both normal pregnant and occluded females.

Heavy metals

The mean levels of Hg, Se, Cd, Zn and Cr in the ringed seal liver in the Gulf of Bothnia are given in Table 3 by sex and the reproductive category of the female. The only differences between the sexes emerged for Hg ($t=2.69$, $p<0.05$) and Se ($t=2.88$, $p<0.01$), the levels in the females exceeding those in the males. The only difference between the pregnant and non-pregnant females occurred in the case of Zn ($t=2.41$, $p<0.05$), the pregnant ones having the higher levels.

The levels of heavy metals were not dependent on the age of the seal, except in the case of Zn (Fig. 2).

Correlations between different elements

Correlations between PCBs, tDDT and heavy metals are indicated in Table 4. It must be recognized that existing correlations may show real cause-effect relations, but also only coincidence.

Firstly, a high positive correlation was found between the levels of PCBs and tDDT (Helle et al., 1981), but PCBs did not correlate significantly with

any of the heavy metals. An indicative negative correlation was found between tDDT and both Hg and Se ($r=-0.370$ and $r=-0.359$ respectively; in both cases $p<0.10$), although the two specimens with extremely high DDT and low Hg and Se may exercise too heavy a weight on the correlation.

An extremely high positive correlation was found between Hg and Se, while no differences existed between the sexes or the reproductive categories (Fig. 3). Cd showed an indicative positive correlation with both Hg and Se and a significant one with Zn (Fig. 4), but with no differences between the various groups.

DISCUSSION

General levels of toxic components in the Baltic seals

Good conditions for the accumulation of organochlorines into seals prevail in the Baltic Sea, an inland sea with a relative small water mass surrounded by densely settled and industrially developed coastlands. Higher mean levels of PCBs in pinnipeds occur only in the North Sea and higher tDDT levels only on the Californian coast of the Pacific Ocean (Holden, 1978). Even taking into account the decrease in levels of organochlorines in the seals of the Gulf of Bothnia during recent years (Helle et al., 1981), these are still quite high, especially in the case of PCBs, when compared with most sea mammal populations in the world.

The mean level of total mercury is somewhat lower than was discovered 3 years earlier in the same population in the Gulf of Bothnia (see Kari & Kauranen, 1978), but both figures are higher than those found in the Gulf of Finland (see Karppanen & Henriksson, 1974). The present Hg levels in the Gulf of Bothnia remain clearly below those found in the mid-1960s (see Häsänen, 1975), before the bans on its use were introduced in the pulp industry, and below those found in ringed seals in the closed lake system of Saimaa in Finland (Kari & Kauranen, 1978).

The Hg levels in the Gulf of Bothnia are not especially high, however, and markedly higher levels have been reported in pinnipeds, e.g. on the Californian coast, in some places in Canada, and in the North Sea (for review, see Holden, 1978). Seals with clearly lower levels of Hg are found in eastern Canada, arctic Alaska (Holden, 1978) and Greenland (Johansen et al., 1980).

The only reports on selenium concentrations in seals in the Baltic Sea originate from the same ringed seal population in the Gulf of Bothnia 3 years earlier. In that time the levels were about twice as high as the present ones (see Kari & Kauranen, 1978), as was also the case with Se levels in the Saimaa lake system (Kari & Kauranen, 1978). This is natural when we remember the higher respective Hg levels and the strong correlation between Hg and Se. The levels of Se in the North Sea seals (Reijnders, 1979) and on the Californian coast (Martin et al., 1976) also exceed the present figures, but a large material of ringed seals from arctic Canada suggests concentrations at about the same level as in the Gulf of Bothnia (Smith & Armstrong, 1975).

Cadmium levels have not been reported earlier for the Baltic seal. The present figures represent a rather average level, and markedly higher concentrations have been found e.g. in Californian sea lions (Zalophus californianus), 5-fold on average (Martin et al., 1976), and in the ringed seal in Greenland, 10-15-fold on average (Johansen et al., 1980). Johansen et al.

(1980) considered that one reason for the extremely high Cd levels in Greenland might be a species-specific feature, but the present results for ringed seals in the Gulf of Bothnia indicate that it may not be a question of species-specificity. The levels of zinc in the present material are lower than have been reported anywhere else on average.

Distribution of toxic components in the seal population

Dependence on age

The levels of PCBs and tDDT are dependent on the age of the seal in some populations, although sometimes this dependence is found only in males, and sometimes none can be found at all (for review, see Reijnders, 1979). The above dependence still emerged in the ringed seal males in the Gulf of Bothnia in 1975 (Helle et al., 1976a), but failed to appear in the latest results (Helle et al., 1981).

Since the methods of capturing the seals have remained comparable over the periods studied and the ringed seals have originated most probably from same localities, it seems possible that the rate of depletion of the toxins has reached about the same level as the intake, or even exceeded it. The decrease in DDT levels has been clearer than that in PCBs (Table 1). This is a natural sequence of events, when we recall the earlier decline in DDT levels in the lower organisms of the Baltic environment (see e.g. Miettinen et al., 1981), and the fact that DDT may have a higher rate of depletion compared with PCBs.

Several studies have revealed that Hg levels are positively dependent on the age of the seal (e.g. Koeman et al., 1975; Drescher et al., 1977; Reijnders, 1979; McKie et al., 1980). The present ringed seal material failed to confirm this, but this could be due to the lack of pups and subadults in this material (see Fig. 2). The same is true for selenium, which was expected on the basis of the well-known co-occurrence of these elements in marine mammals (see above).

Cadmium levels have been found to be age-dependent in harbour seals (Drescher et al., 1977) and porpoises (Phocoena phocoena)(Falconer et al., 1980). The present independence may again be due to the absence of young specimens, and thus the results are not strictly comparable. On the other hand, the present finding that zinc is negatively age-dependent is not well-known.

Occurrence of components by sex and the reproductive category of the female

It has been stated earlier that the reproductive failures in the Baltic seal populations are linked in some way with high levels of PCBs (Helle et al., 1976a, Olsson, 1977), and this hypothesis, built up on the basis of observations made from seal populations, mostly the ringed seal population in the Gulf of Bothnia, received support from laboratory experiments performed with minks (Mustela vison)(e.g. Jensen et al., 1977). It has been stated quite correctly, however, that the detrimental effects of PCBs on seal reproduction have not been attested definitively (e.g. Holden, 1978, Reijnders, 1979). The present material similarly fails to confirm this point. On the contrary, the problem seems to be still more complicated than was thought earlier. For example, high levels of both PCBs and tDDT are found in females with one uterine horn occluded, but the lowest figures of all occur among the females with both horns occluded (Helle et al., 1981), i.e. those females which had been suffering from the pathological disturbance for the longest time. Present information would suggest that the levels in

question ought to behave more like those observed in the males, i.e. increasing with time, or else decrease more slowly than the levels in normal breeding females, which always transfer part of their burden of toxins to their pups (see e.g. Addison & Brodie, 1977). It is true that in the case of heavily polluted areas such as the Baltic Sea, parturition and lactation may have only a slight and temporary effect on the contaminant burden (see Reijnders, 1979). Apparently our knowledge of the accumulation and depletion of PCBs and tDDT in seals is still far from complete, particularly in the case of Baltic seal populations suffering from physiological dysfunctions.

The possible role of PCBs in connection with reproductive failures in the Baltic seals have been doubted, e.g. because much higher PCB levels have been reported in North Sea seals but not a single occluded uterus has been discovered (see Reijnders, 1979). Firstly, it must be said that studying only the mean levels of toxins and studying each toxin separately is too simply an approach. The environmental factors in the Baltic Sea are different from those prevailing in the oceans, and detrimental effects may remain concealed for a longer period of time, or else they may not arise at all under some other conditions, or they may take the form of some other kind of failure. In Californian sea lions the defect has proved to involve abortions (e.g. Martin et al., 1976), and in the Wadden Sea the harbour seals suffer failure to implant or early resorption (e.g. Reijnders, 1979). At the same time, uterine occlusions were not the only reproductive disorders in the ringed seal population in the Gulf of Bothnia (Helle, 1980b).

One theoretical possibility not absolutely excluded to date would be an epidemic, which could have a geographically restricted distribution, at least at the beginning, in spite of possible favourable conditions prevailing in other localities.

Laboratory experiments with minks have demonstrated that specimens fed heavily with PCBs become more susceptible to an accumulation of Cd in the kidneys (Olsson et al., 1979), and it is important to take combined effects of this kind also into consideration when discussing these problems. The present liver material does not show any effects of this kind.

The molar ratio of 1:1 between Hg and Se is the best documented co-occurrence of heavy metals in marine mammals (e.g. Koeman et al., 1973; Reijnders, 1979), and it is also known to occur in reproductively disturbed populations. For instance, Martin et al. (1976) found a slight Hg excess in females with both normal partus and abortion, and this was also true in the present material. Cadmium is also known to correlate with Se (e.g. Parizek et al., 1971). Indeed Martin et al. (1976) found that Cd showed a strong correlation with both Hg and Se in females with normal partus, but failed to find this in abnormal female sea lions. Both of these correlations were met with at an indicative level in the total material of the present study. The antagonistic role of cadmium and zinc is well-known (e.g. Parizek, 1957), but as far as the author knows the present finding of a correlation between them is rarely observed in marine mammals.

Martin et al. (1976) were able to show that huge absolute levels of heavy metals exist in marine mammals without producing any ill-effects, but that an imbalance between certain components at much lower levels was fatal for successful breeding. This was the consequence of bromium deficiency in particular. Unfortunately this aspect can not be studied in the present material.

Although the present paper provides some totally new information, especially concerning the heavy metals in the Baltic seal populations, this does not

solve the riddle of the reproductive failures. The currently changing levels of organochlorines in the Baltic environment will further hamper any efforts to resolve the problem. On the other hand, useful information may be obtained by monitoring the decrease in organochlorine levels and recording any changes in seal reproduction in detail, without ignoring the role of other pollutants.

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Table. 1. Mean levels of PCBs and total DDT (mg/kg of extractable fat) in blubber of ringed seals from the Gulf of Bothnia.

Time of sampling	1972-73[1]	1973-74[2]	1975[3]	1977[4]	1978-80[4]
No. of specimens	10	40	85	15	27
tDDT	120	110	115	118	38
PCBs	50	69	95	135	77

[1] Karppanen & Henriksson, 1974

[2] Helle et al., 1976b

[3] Helle et al., 1976a

[4] Helle et al., 1981

Table 2. Mean levels of PCBs and total DDT (mg/kg of extractable fat) in blubber of ringed seals from the Gulf of Bothnia, by sex and reproductive category of the female.

	1975[1]			1978-80[2]		
	N	PCBs	tDDT	N	PCBs	tDDT
Females						
Pregnant	24	73	88	6	74	33
Non-pregnant with uterine occlusions	29	110	130	18	107	42
Non-pregnant with normal uterus	8	89	100	8	71	78
Males	24	100	130	10	119	121

[1] Helle et al., 1976a

[2] Helle et al., 1981

Table 4. Correlations between levels of organochlorines and heavy metals in ringed seals from the Gulf of Bothnia in 1977-78 (n=22). Levels of PCBs and tDDT are from Helle et al. (1981).

	PCBs	tDDT	Hg	Se	Cd	Zn
Cr	-0.057	0.043	-0.239	-0.213	-0.153	0.118
Zn	-0.202	-0.228	-0.091	0.012	0.515^{+}	
Cd	-0.150	-0.165	0.405^{o}	0.396^{o}		
Se	-0.073	-0.359^{o}	0.956^{+++}			
Hg	-0.109	-0.370^{o}				
tDDT	0.788^{+++}					

^{o} $p<0.10$, $^{+}$ $p<0.05$, $^{+++}$ $p<0.001$

Table 3. Mean levels of mercury, selenium, cadmium, zinc and chromium (mg/kg wet weight) in ringed seal liver from the Gulf of Bothnia in 1977-78, by sex and reproductive category of the female.

		mean ± SD range	mean ± SD range	mean ± SD range	mean ± SD range	mean ± SD range
Females, in total	17	57.1 ± 37.1 3 - 148	17.8 ± 11.1 2 - 48	0.78 ± 0.26 0.34 - 1.50	30.6 ± 5.1 24 - 40	0.056 ± 0.036 0.015 - 0.150
Pregnant	5	52.4 ± 13.9 36 - 74	18.6 ± 5.1 12 - 25	0.89 ± 0.36 0.62 - 1.50	34.4 ± 3.8 30 - 40	0.053 ± 0.040 0.015 - 0.100
Non-pregnant with uterine occlusions	12	59.0 ± 43.8 3 - 148	17.6 ± 13.1 2 - 48	0.74 ± 0.22 0.34 - 1.20	29.1 ± 4.8 24 - 35	0.058 ± 0.035 0.020 - 0.150
Males	5	29.4 ± 11.2 16 - 47	9.6 ± 2.3 6 - 12	0.74 ± 0.31 0.34 - 1.20	31.2 ± 4.0 27 - 35	0.056 ± 0.056 0.015 - 0.060
In total	22	50.8 ± 34.8 3 - 148	16.0 ± 10.4 2 - 48	0.77 ± 0.27 0.34 - 1.50	30.8 ± 4.8 24 - 40	0.056 ± 0.039 0.015 - 0.150

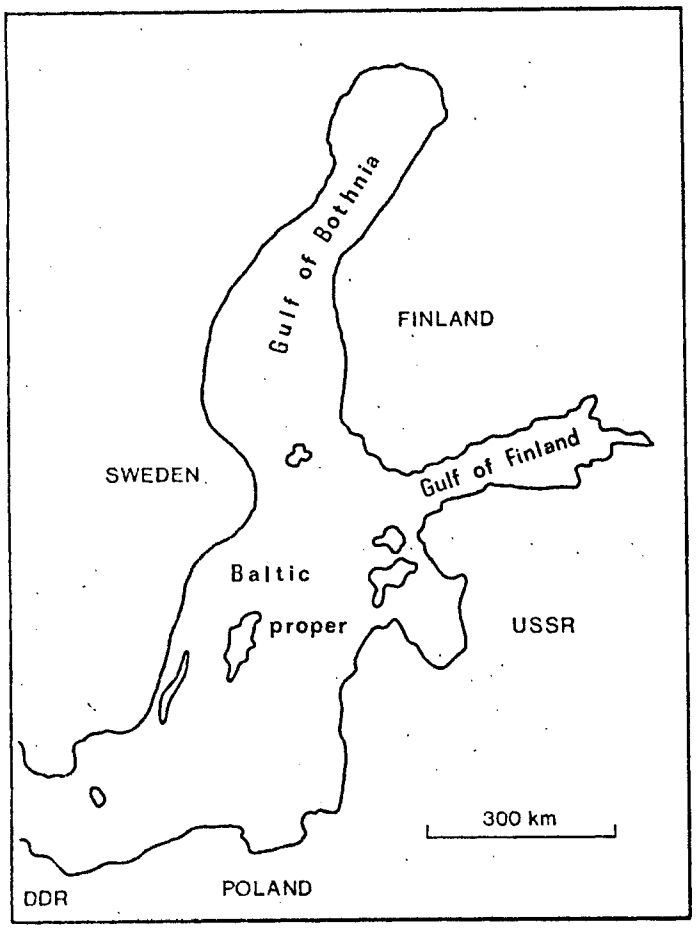

Fig. 1. The Baltic Sea.

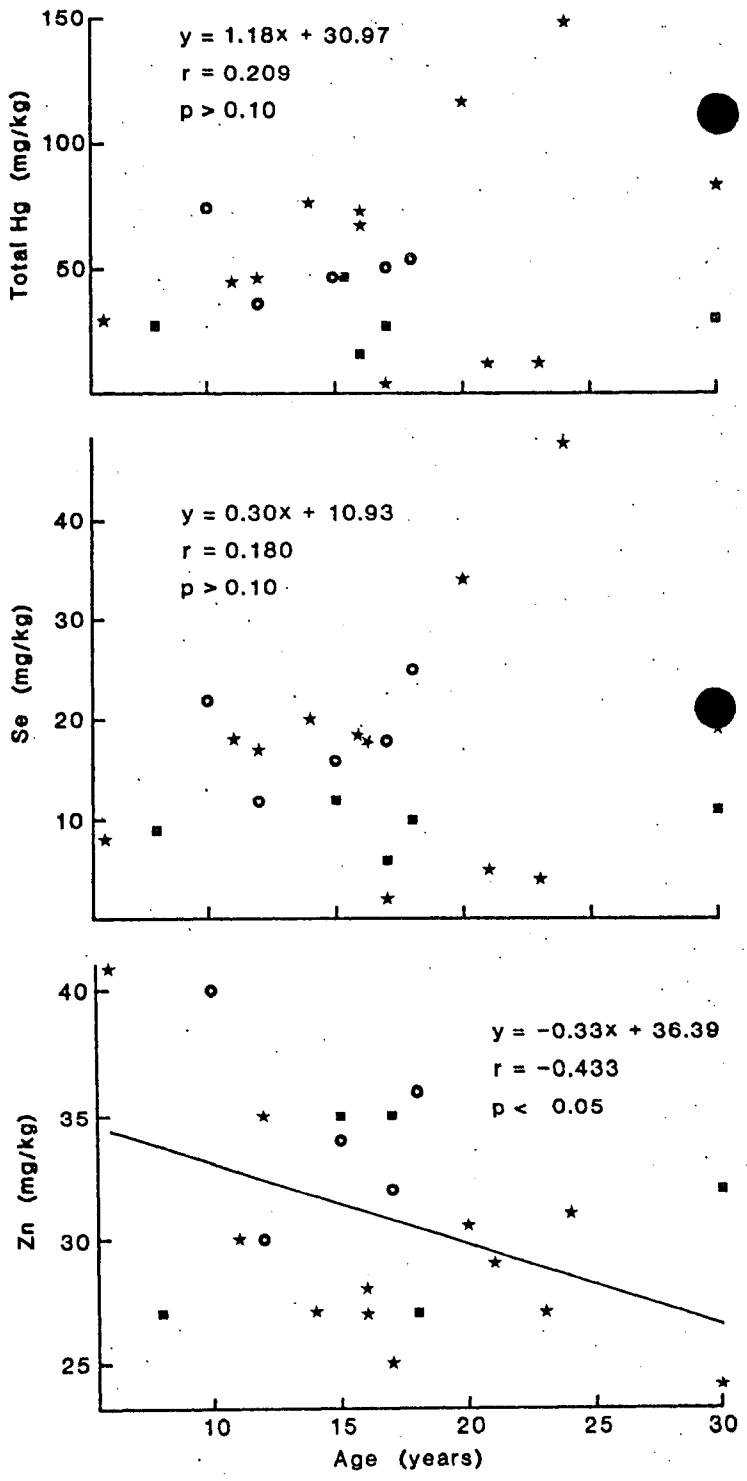

Fig. 2. Relationships between total mercury, selenium and zinc and age of the ringed seal from the Gulf of Bothnia in 1977-78 (mg/kg liver wet weight). ■ males; ✪ pregnant females, ★ females with uterine occlusions.

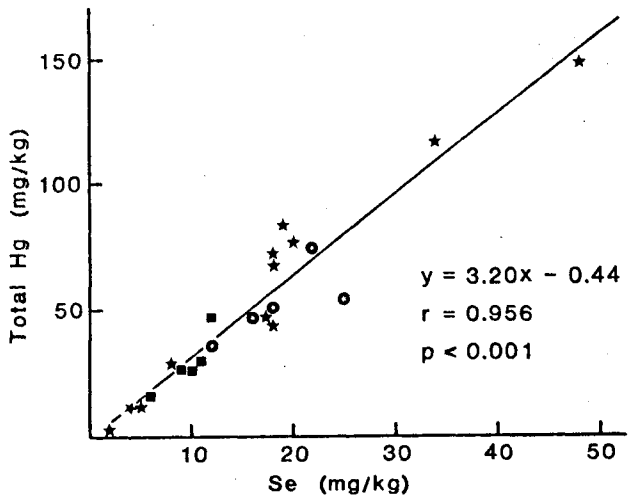

Fig. 3. Relationship between total mercury and selenium in ringed seals from the Gulf of Bothnia in 1977-78 (mg/kg liver wet weight). Symbols as described in the legend for Fig. 2.

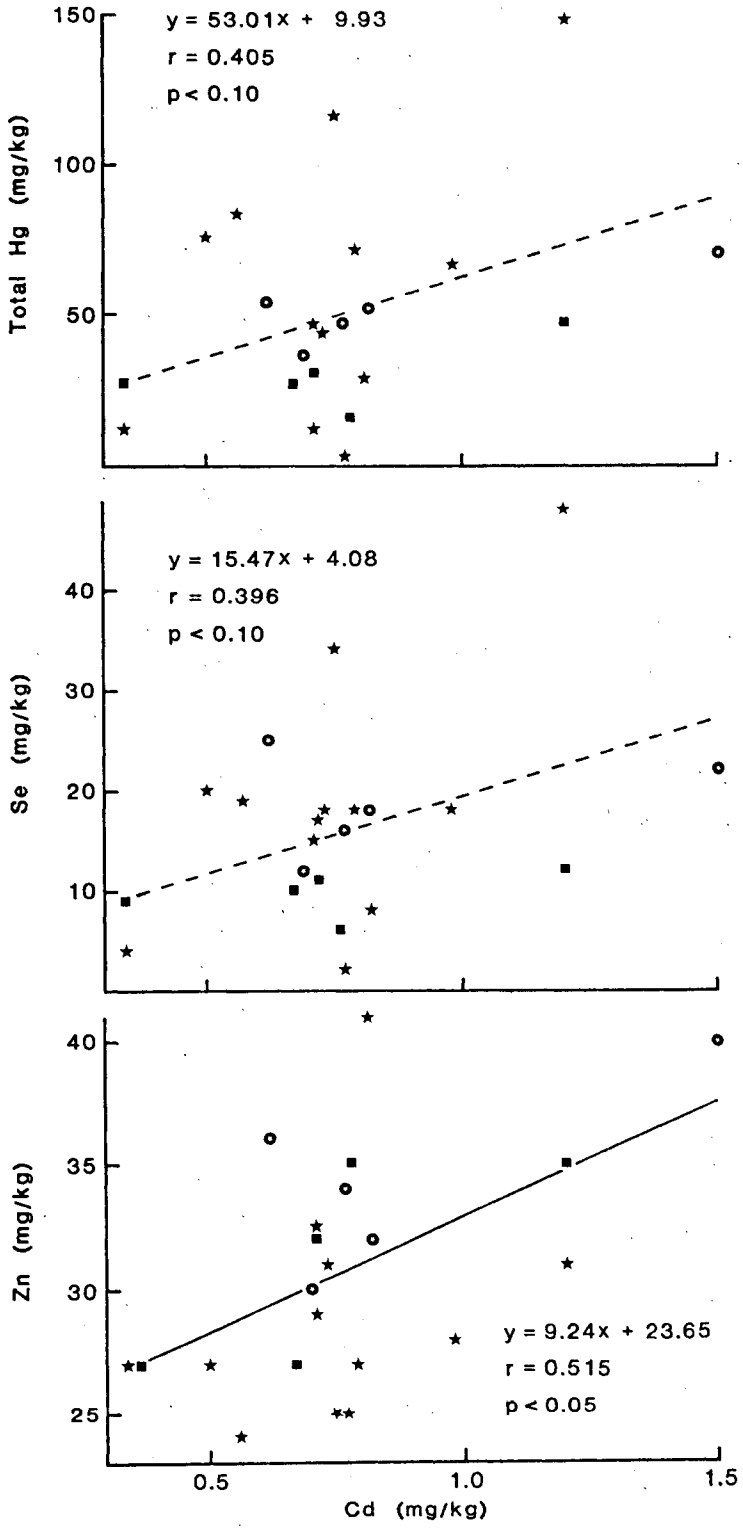

Fig. 4. Relationships between total mercury, selenium and zinc and cadmium in ringed seals from the Gulf of Bothnia in 1977-78 (mg/kg liver wet weight). Symbols as described in the legend for Fig. 2.