International Council for the Exploration of the Sea

C.M.1971/E:31
Fisheries Improvement Committee

Ref. Special Meeting on Cod and Herring

DDT and PCB in Baltic fish

by

G. Otterlind, S. Jensen and M. Olsson[x)]

Abstract

A preliminary account is given of a large-scale investigation of the levels of DDT- and PCB-compounds in sea fish from Swedish waters, mainly the Baltic Sea. About 1,800 analyses have been made, 1,500 thereof from the Baltic, comprising c. 800 herring and 450 cod and smaller numbers of other species. The results obtained confirm that the pollution by the DDT- and PCB-compounds is serious in the Baltic. High levels were found in muscle tissue (fillet) of fat fish such as herring and salmon and in liver of lean fish as cod. - The regional distribution of the compounds is described. The highest levels of DDT in herring are to be found in specimens from the southern and central Baltic, from E of Bornholm to SE of Gotland (mean level 40-50 ppm on fat weight basis or c. 2-3 ppm on fresh fillet tissue). The contents of PCB-compounds do not seem to have the same regional distribution and the mean values for herring are approximately the same in the main parts of the Baltic, E of Bornholm (c.15 ppm on fat basis and c. 1 ppm on fresh weight basis). In cod the mean levels of DDT- and PCB-compounds in the musculature samples are lower, for fish from the Bornholm-Gotland area below 20 ppm on fat basis and below c. 0.25 ppm in fresh tissue. In cod liver, however, the level on fat weight basis for DDT-compounds varied in the present material between 19 and 64 ppm (on fresh weight 4.4 - 18.0 ppm). For the PCB-compounds the corresponding data are 4.1 - 32 ppm (on fat weight basis) and 1.4 - 9.2 ppm (fresh weight). Swedish authorities have declared liver from cod caught in the Baltic unfit for human consumption.

The relations between the age of the fish and the levels of DDT- and PCB-compounds are considered as well as the importance of migration habits. High levels in the Bornholm Basin also in young herring and cod confirm the impression that the environmental pollution is greatest in this area. The percentages of the metabolites DDE and DDD of the total DDT contents in fish of different ages and from different areas are discussed.

Introduction

A report of the occurrence of DDT and its metabolites as well as PCB substances in fish and other organisms from the Swedish coast and sea areas, has been published previously (Jensen et al. 1969). The results were based upon about 180 analyses made on material taken mainly from the Baltic during the period 1965-68. The material from the Baltic showed higher values of the compounds

x) Mr. G. Otterlind, Inst. of Marine Research, S-453 00 Lysekil, Sweden

Mr. S. Jensen, Wallenberg Laboratory, L:a Frescati, S-104 05 Stockholm, Sweden

Mr. M. Olsson, Swedish Museum of Nat. Hist., S-104 05 Stockholm, Sweden

than material from the waters off the Swedish west coast and higher also in comparison with published data on the North Sea, the Atlantic and the west coast of North America. In fish, the values of PCB-and DDT-compounds seemed normally to be 5-10 times higher in the Baltic. In comparison with the residue levels in fish, the values were considerably higher in seals and guillemot (Uria aalge); in heron (Ardea cinerea) and white-tailed eagle (Haliaeetus albicilla) the values obtained were more than 100 times higher.

Relatively high contents of dieldrin were later found in herring from the southern and central parts of the Baltic, especially in the Stockholm archipelago (Westöö and Norén, 1971). As a rule, the levels in fresh tissue were below 0.05 ppm. In the present investigation the levels of dieldrin were not examined, since routine analyses of dieldrin would have delayed the work considerably.

Fish species with high contents of fat in muscle tissue (herring and salmon) proved to have higher levels than lean fish (e.g. cod and flounder), examined on fresh weight of fillets. The residue levels of DDT- and PCB-compounds in muscle tissue also varied with the contents of fat of the individual fish. For instance the content of fat in the fillet of herring was between c. 1 and 15 %. For these reasons, the contents of fat in the samples were always examined, and the levels of DDT- and PCB-compounds were examined also on fat weight basis.

In the above mentioned but limited fish material analysed there were indications that the levels of both DDT- and PCB-compounds increase towards the southern Baltic and that PCB in coastal areas is sometimes giving strong evidence of local pollution. In correspondence with the previous well-known principle, an increasing concentration of DDT- and PCB-compounds could be observed as we get higher up in the food-chains, from fish to seal and from fish to bird (as mentioned above). Some data indicated that the content of the metabolite DDE (of DDT) was increasing in higher links in the food-chain. - In the present report mainly the continued investigations concerning DDT- and PCB-compounds in sea fish will be discussed.

Methods and material

Grants from the National Swedish Environment Protection Board in 1969 made it possible to extend the investigations of the remarkably high levels of DDT- and PCB-compounds in Baltic fish. The sampling and analytical methods described earlier (Jensen et al. 1969) were applied on the whole. For instance, the residue levels were determined on extractable fat basis, but are also shown on fresh weight basis. Samples from fish fillet were used as a standard; and, to an increased extent, also liver samples were taken of such lean fish as cod. A smaller number of analyses were made on gonads and other tissues.

The investigations on fish included samplings 2-4 times a year in 16 sea areas along the Swedish coast, from the Bothnian Bay in the north via the Sound to the Skagerrak in the west (see fig.1). Most analyses were made on fish from the Baltic. Every series of samples usually includes 15 specimens, which are analysed separately. Furthermore, some additional material was deep-frozen for complementary analyses, if such are found necessary. The most important subjects of investigation were herring (Clupea harengus) and cod (Gadus morhua)(see table 1). On a smaller scale, samples were also taken of salmon (Salmo salar), white-fish (Coregonus lavaretus et al.), vendace (Coregonus albula), sprat (Sprattus sprattus),flounder (Platichthys flesus) and plaice (Pleuronectes platessa) - for the results, see table 4. The first plankton sample was analysed, as well as four specimens of porpoise (Phocaena phocaena) from the Baltic. During 1971 samples of plankton were collected to a greater extent, as well as samples of the bottom fauna. By using special filters samples of the water have been collected from the investigation areas in order to develop a routine analytical method for water (including organic matter). In addition to the investigations mentioned, concerning sea fishing proper ("the sea investigation"), samples were also taken at stations in the archipelagos and by the coast ("the coast investigation"), to study principally the effects of local pollution. In these investigations, yellow eel and pike were used for the analyses. The coast investigation will be reported in another context. It should be observed that analyses of sea fish caught along or near the coast are included to a significant degree in the sea investigation. The total number of analyses of cod and herring are for the moment 1,482, of which 1,248 are from the Baltic. Of the latter, 449 are cod and 799 herring. A small number of liver and gonad analyses exist as well. In addition c. 300 analyses were made on the other above mentioned species (to these must be added c. 900 in the coast investigation).

Although a relatively large number of analyses made on sea fish from Swedish sea areas exists, it does not mean that final results can be reported. For technical reasons and lack of capacity the analyses lag behind the sampling, and it was not until 1971, therefore, that samples could be chosen to complete the results of analyses already available. Generally speaking, the levels of DDT- and PCB-compounds seem to vary greatly with area, age of the fish and species. Different migration and feeding habits, partly also seasonal variations seem to be of importance in this connection. It is often difficult or even impossible to estimate which factors are the most important for the residue levels in a certain series of samples or in the individual fish. This report must therefore, be considered as a preliminary one. The analyses of statistical data will be made - so far possible - on a more complete material. However, some general trends can be traced and an account is given of them here in tables 1-4 and figs. 1-5. The main stress is laid on herring, which are to be found within the whole water area, though with different populations. Cod is mentioned, too, but the conditions of this species diverge by, among other things, its low fat content in muscle tissue (fillet) and the great importance of the liver as a fat depot. Therefore the cod material is less valuable than the herring material. Further analyses are needed of cod, especially of the liver.

Results: 1. Herring

Fig. 2 shows the mean value in ppm for all analyses of DDT-(incl. DDE and DDD) and PCB-compounds in muscle fat from fillet samplings of herring in different sea areas (nos. 1-15 in fig. 1) from the Bothnian Bay in the north to the Gothenburg area in the west. DDT (incl. metabolites) show the highest values in the central and southern Baltic, east of Bornholm (nos. 8-11) with a mean value of approx. 40-50 ppm on fat weight basis (approx. 2-3 ppm on fresh tissue). To the west of Bornholm the residue levels decrease (in area 12) and they are considerably lower off the West Coast (c. 2-3 ppm on fat basis, 0.2-0.3 ppm fresh weight). The levels of DDT in areas 1-5, from the Bothnian Bay to the Åland Sea (mean values c. 15 ppm and c. 0.5-1.0 ppm respectively,) are lower than in the area from Gotland to Bornholm (nos. 8-11).

The level of PCB does not vary so much and the mean values in the Baltic are approximately the same except in area 12, west of Bornholm. In the area east of Bornholm, the level of PCB is about 16 ppm on extractable fat basis (c. 1 ppm on fresh weight). The highest mean value, 24 ppm on fat basis, was measured in the Stockholm archipelago (area 6). To the west of Bornholm the level decreases as it does for DDT, and the decrease is evident also off the West Coast. No new sample of herring from the Sound has yet been analysed - one high PCB value was noted earlier (Jensen et al. 1969). PCB shows values equal to or higher than those for DDT in the Gulf of Bothnia

(c. 15 ppm on fat weight basis) and on the West Coast. High values in single samples from both the East Coast and the West Coast indicate influence of local pollution sources.

According to fish tagging experiments, herring from the Gulf of Bothnia and also to a great degree from the inner parts of the Stockholm archipelago do not move south of the Åland Sea (Otterlind 1961 a). However, within the Åland Sea local and northern populations mix also with fish migrating to and from the Baltic proper. The last-mentioned fish can also be met with in the outer parts of the Stockholm archipelago. Baltic herring from the northernmost areas (nos. 1-4) can be considered bound to these areas and without addition of fish from the south. In the inner parts of the Stockholm archipelago, however, older herring may at times come in from the south. In the Baltic proper, spring-spawning herring populations of a migrating type dominate, and during summer/autumn they mix in the southern Baltic, mainly to the east of Bornholm. These waters are a very important feeding area for different populations, also of an autumn-spawning type. To the west of Bornholm are primarily herring which breed there, or which have moved from the Belt Sea and the south part of the Sound.

The sampled herring were analysed in respect of age by the winter-rings of the scales. The actual age of spring-spawners may vary between the numbers of rings given in figs. 3-4 and table 2 and the next higher number. Thus, fish with the same number of winter-rings may have been born in two successive years depending upon when the sample was taken (before or after the establishment of the winter-ring for the year). The age of the autumn-spawners, which up to now have been included to only a slight extent in the samples (mainly in those from the southern parts of the Baltic) may be one year higher than for the spring-spawning fish with the same number of rings. During the first part of the sampling, every series of 15 fish was chosen so that, as far as possible, different sizes and ages were represented. Such samples form the main part of the present series of analyses. Later on, two series often were chosen from every catch after the age-examination, one with younger fish and one with older. The relation of the age to the levels of DDT- and PCB-compounds is shown in figs. 3-4 and table 2.

Fig. 3 shows the mean values of DDT and PCB per group of herring of approximately the same age, where all the samples from different times and localities in the most important investigation areas have been combined. Here, as well as in the other diagrams, the substances are measured on fat weight basis in samples from fillet. The level on fresh weight basis shows mainly the same trends but a certain variation is due to differences in fat content. Although the material within the respective areas is heterogeneous and partly insufficient for comparing mean values, a trend towards higher levels of DDT and PCB with increasing age can be distinguished. This need not necessarily be the result of a longer exposure time only. Also the occasions of the exposure must be taken into account. The relation between age and increased levels of DDT-compounds can be seen most clearly in fish from the central and southern parts of the Baltic proper, area 8 (SE Gotland) and area 11 (E Bornholm). Possibly the PCB-compounds show less connection with age than the DDT content.

A comparison between fish of the same age in the different areas shows, on the whole, the same variations of the levels of substances as in fig. 2. This does not mean that the age structure of the population is without importance for the general trend in fig. 2. In principle it may be said that the average age of the herring in the Baltic increases from the south to the north, parallelly with a decrease of the growth rate. This implies that the age structure involves lower contents on an average to the south in general and west of Bornholm, too, but higher values north of

Bornholm. Thus, in relation to the conditions of the area Gotland-Bornholm the difference is equalized somewhat to the north, while it is augmented to the west of Bornholm (cf. also migration effects below).

In table 2 some comparisons are shown between samples of herring of different ages, caught within the same area and at the same time. The samples from areas 1 and 4 consist (see above) of herring which have had no contact with the Baltic proper. The same will surely be valid for young herring from area 5 (Svartklubben 1.11.1969) but perhaps, partly, not the older herring from the same locality and day. The difference between the levels of DDT and PCB in these two series of samples is significant on the 2.5 % level. The same is implied for the series from area 8, while the differences in the other areas are not statistically demonstrated. But the relation between age and contents of DDT and PCB can also be traced in the compared series from the areas 1, 4 and 11 (E Bornholm). This is valid on both fat basis and wet weight basis. However, two series of samples from the Karlskrona archipelago of fast-growing, spring-spawning herring show negligible differences in mature fish of 2-3 years compared with fish of 5-6 years of age (the mean value for DDT: 56 and 62 ppm respectively and for PCB 18 and 14 ppm). Here the young herring most probably grow up in the Bornholm Basin (N and E Bornholm).

Another observation that can be made is that of the level of total DDT-compounds, the proportion of the metabolite DDE seems to be lower on average, while the level of non-metabolized DDT is higher in young herring than in older fish. This is probably also one reason why the results of the analyses of fish from the northern areas show a higher proportion of DDE than in the south. Parallelly the analyses from the southern areas show higher proportions of DDD than those from the northern. This may also be the result of a higher biological activity in the more warm and nourishing water in the southern Baltic compared with the Gulf of Bothnia. Water-living bacteria have been shown to metabolize DDT into DDD to a higher degree than into DDE (Cope and Sanders 1963, Matsumura et al. 1971). If most of the pollution of the Baltic (incl. the Gulf of Bothnia) has its origin in the southern parts, the DDT-substance in the northern parts may be due partly to secondary dispersion from the south (see below). This dispersion may also give a higher proportion of DDE by metabolizing processes during the transport. As DDE is more stable than DDT and DDD, the length of the metabolization period, as well as the age of the fish, should encourage a higher proportion of DDE.

Fig. 4 shows the residue levels in separate series of herring. Samples in the age groups from area 11 east of Bornholm (positions of localities abbreviated). Here we can see that even young herring may show high values. This is apparent especially in the sample from SE Neksö, 9.6.1970. One specimen with only one winter-ring had a level of 140 ppm of DDT and 67 ppm of PCB on fat basis (on wet weight 3.5 and 1.7 ppm respectively). Also herring with 2-3 winter-rings had high values. In the latter case the herring are probably autumn-spawners, so the examined age may be 1-2 years higher than the number of winter-rings. Occassionally DDT-contents of over 100 ppm on fat basis have been observed further north, as far as the inner parts of Stockholm archipelago (area 6). As a rule this has been observed in older fish, probably migrated from the south, but also in one specimen from the Västervik archipelago with only one winter-ring a level of 107 ppm was measured (the content of PCB was then 140 ppm). However, it is in the south Baltic, east of Bornholm, where the greatest number of high contents have appeared (cf. fig. 4). The highest value here, 250 ppm of DDT-compounds (7.7 ppm on wet weight basis), was found in a herring from 12.6.1969, caught ENE of Christiansö and due south from Öland at a depth of about 70 meters. The fish had eight winter-rings and was probably a spring-spawner.

Further material of fish, plankton and bottomfauna from the Bornholm Basin will be analysed. However, it is evident already that the occurrence of DDT-compounds in herring is highest in the eastern part of the southern Baltic and after that in the central Baltic (the Gotland Basin, E Gotland). As already mentioned, the southern Baltic, mainly east of Bornholm, is a very important feeding area for the herring populations that spawn along the east coast of Sweden as far as the Åland Sea (Otterlind 1961 a, 1962). Especially older herring from this part spend their summer/autumn in the southern Baltic. Therefore material of older, spawn-migrating herring caught in the northern Baltic proper might be affected by the pollution in the southern Baltic and thus it appears that a certain transport of DDT-compounds from south to north may be caused by the spawning migration of the herring. The great concentration of older fish on feeding migration to the southern part during the summer/autumn may also by the age effect lead to a small temporary rise of the DDT-level of the herring catches here.

The PCB-compounds do not seem to have such a regional distribution as the DDT-compounds. The levels of PCB show a peak in area 6 (the Stockholm archipelago). The lowest values in area 12 (W Bornholm) form a transition to the low values in herring from waters off the West Coast (cf., however, the values in cod). The contents of DDT and PCB in the Stockholm archipelago have been commented on in an earlier report (Olsson et al. 1971).

2. Cod

The analysed material of fillet samples of cod give partly another picture than that of herring. As a rule the levels of DDT- and PCB-compounds on fat basis are lower and the mean value in the area Gotland-Bornholm is below 20 ppm (cf. table 1 and fig. 5 a nos. 8-11). Since the fat content in muscle tissus in cod is low, usually 0.5-1 % in this material (it is highest in young cod), the levels in fresh tissue are also low in fish from the Baltic, below c. 0.25 ppm, but high in the liver (see below). Off the West Coast the values are still lower. A comparison of the mean values between different catch areas (fig.5 a) shows that the level of DDT becomes lower W of Bornholm (no.12 in fig.5 a) compared with the rest of the Baltic, but no pronounced peak is observed for the area between Gotland and Bornholm (nos. 8-11). The level of DDT is also lower in the Sound (no. 13) and is further reduced off the Swedish west coast (nos. 14-16), where the mean value is c. 3-4 ppm on fat basis (on fresh tissue c. 0.02). In the Sound, however, the level of PCB increases and also reaches relatively high values off the West Coast (c. 13 ppm on extractable fat basis, c. 0.07 ppm on fresh tissue). The level of PCB is distinctly higher than the level of DDT in these areas. The samples are mainly from coastal waters. In material from the waters to the west and to the east of Bornholm the level of PCB is about the same or somewhat higher than the level of DDT. A series of samples from the Åland Sea also gave somewhat higher levels of PCB than of DDT.

The material analysed did not reveal any clear relation between the levels of DDT- and PCB-compounds in muscle tissue and the age of the fish. The determination of age in cod from the Baltic is rather uncertain, especially that of older fish - due to vague otoliths and varying time of spawning - and the data on age are therefore approximate only. What is most remarkable in the cod material is, however, that occasionally very high contents of DDT- and PCB-compounds have been observed in young cod aged of 0-2 years among otherwise low values: levels of up to 110 and 79 ppm on fat basis (in mature cod the maxima were 92 and 50 ppm respectively). This was the case in principally three series from the area ENE of Christiansö (south of Öland) and SE of Neksö in June 1969 and 1970. Samples of about the same age in October 1969 and March 1970 from the first-named area gave consistently low values. A possible explanation might be the varying feeding habits of cod - even with different bottoms. For young fish the nourishment consists largely of both bottom-living and more or less planktonic crustaceans, which are of small or at any rate less importance to the adult fish. It should also be pointed out that adult cod from various regions gather to spawn within the area in question during spring-early summer. The deep basin in the east of Bornholm is more a spawning area than a nourishment area for cod. For herring, however, it is mainly a feeding area. Nevertheless, there might be a possibility of a direct up-take of DDT- and PCB-compounds, for instance, through the gills. In this connection the different basal metabolism of the fish species may be of importance.

The divergence of the levels of DDT- and PCB-compounds in muscle tissue in the Baltic cod from different areas compared with those in herring, must also be related to the generally more varying nourishment of the cod (free living and bottom-bound evertebrates and fish) compared with the mainly plankton-eating herring. In this respect, very young cod resemble herring. However, the difference in nourishment between young and old herring is smaller, often non-existent. Further it should be observed that no effective reproduction of cod occurs north of Gotland. Thus, the species is more homogeneous as regards population, although two main populations can be distinguished, with a broad zone of mixing chiefly around Bornholm. Quite likely, one consequence of the mixing of populations might be an increased variation of the contents of DDT and PCB in the specimens. Cod coming from the west, with primarily low levels, may mix with cod from the east with higher levels as well as with fish which have grown up along the coast of the Baltic proper, at times even further to the north (Otterlind 1961 b). This contributes to a levelling-out of the mean level for DDT and PCB in the south of the Baltic, especially in the central spawning area, east of Bornholm.

It is difficult to find any relation between the age of the cod and the proportion of DDE of the total amount of DDT-compounds. However, the older cod in two series of samples from the Åland Sea and the Bothnian Sea show the highest mean values and it is among really young cod in the south of the Baltic that sometimes the very low mean values are to be found. At the same time the quantity of the samples in some of the latter series are too small to allow a reliable estimation of the percentage of the DDT-metabolites.

Parallelly with the sampling of musculature from the fillet, samples of liver in cod were taken for analysis. Contemporary analyses for food hygiene estimation at the National Swedish Institute of Public Health (Westöö and Norén 1971) showed high residues of DDT (including metabolites) and PCB in cod liver from the Baltic. In seven samples levels of 11.3-22.0 ppm of DDT and 2.4-4.9 ppm of PCB on fresh tissue were shown and were compared with three samples showing lower levels in cod liver from the West Coast (2.5-4.1 ppm of DDT and 2.2-3.4 ppm of PCB). (As a consequence of the high DDT contents Swedish authorities have declared liver from cod caught in the Baltic Sea unfit for human consumption and it must not be sold.) Table 3 and fig 5b show analyses on liver of 130 cod. The mean levels on fresh tissue varied for the series of samples between 4.4 and 18.0 ppm of DDT (for individual fish 1.2 - 50 ppm). Corresponding data for PCB are 1.4 - 9.2 ppm (individual values 0.00 - 25 ppm). The mean fat contents in the liver samples in question vary from 20.3 to 36.9 % and the individual liver values of the whole material from 6.3 to 61.2 %.

There are indications that different parts of liver and sometimes different methods of sampling (frozen and nonfrozen material) may show different values of the fat content in the same liver. The samples were taken of livers that had previously been dissected and frozen (from cod where the samples of fillets had been taken of the frozen fish before). To a varying degree the livers were thawed at the weighing of the samples. Two series of liver samples from 15 specimens were analysed, one series was deep-frozen, the other thawed at the sampling. No great difference that could be related to the state of the material could be discerned. Nevertheless, it seems as if the risk of losing fat at the sampling might be greater on thawed material.

The mean values for the residues on extractable fat basis in table 3 show that the level of DDT-compounds in liver is much higher than in muscle tissue in the same specimens. The factor is c. 3-4. For PCB the increase in liver is up to twice compared with the levels in musculature to the east of Bornholm, while none or negligible increase exists in material west of Bornholm. The proportion of non-metabolized DDT may be said preliminarily to be lower in the liver material than in muscle tissue; at the same time there is an increase of the proportion of DDD - an indication of the importance of the liver for the metabolization of DDT-compounds. Of herring, only one series of liver (15 spec.) was analysed (from the Arkona Basin, area 12). In this series the concentration of PCB was much increased, about 9 times, if compared with the mean value in fat of muscle tissue (35 and 4.2 ppm respectively). For DDT-compounds the increase was only about twice (10 and 5.3 ppm respectively). The variation between the catch areas as regards the level of DDT-compounds in liver, shown in table 3 and fig. 5b, can be explained by differences of age and by chance.

General comments

The results of analyses of herring and cod shown in this report confirm that the pollution by DDT- and PCB-compounds in the Baltic, is as serious as the first report (Jensen et al. 1969) indicated. For herring higher values than earlier have been observed in the larger material investigated. As regards other fish species analysed, it may be mentioned that only salmon - as in our previous report - can be said to have obtained alarmingly high values: in individual specimens up to 7.2 ppm of DDT-compounds and 2.7 ppm of PCB on fresh tissue. As a rule, the values of PCB were higher than in the 1969 report. Analyses on herring, cod and other fish in the Baltic, carried out by the National Swedish Institute of Public Health (Westöö and Norén 1971), showed values which lie within the limits of the present material.

Of the present report of the analyses of herring, it appears that the accumulation of DDT- and PCB-compounds may depend upon the age of the fish, but that other factors, mainly the general and local state of pollution are the primary causes of the levels in fish. As concerns cod, the dependence of age is not clear. Besides the state of pollution, the choice of nourishment and also the function of the liver may be of importance. Generally speaking, the variation between areas is less or negligible as regards PCB. The analyses on herring clearly show that the levels of DDT are highest in the south and middle parts of the Baltic proper, mainly in the area SE of Gotland to E of Bornholm. It is possible that the level of PCB is slightly higher here.

The levels of both DDT- and PCB-compounds are clearly lower W of Bornholm, in the Arkona Basin (also in the series of samples from the Belt Sea, SW of Gedser). Also towards the north of the Baltic the level of DDT is lower, especially in the northern part of the Åland Sea and further north, while the decrease in the level of PCB is small or none.

The occurrence of high levels of DDT- and PCB-compounds in the Bornholm Basin (E Bornholm) also in young cod and young herring indicates that the environmental pollution is greatest within this area. The occurrence further north of herring with relatively high levels (in the Västervik area, area 7, and in the inner parts of the Stockholm archipelago, area 6) chiefly concerns older fish migrating from the south. However, local sources of pollution obviously have effects in the inner parts of the archipelagos. Occasionally high levels of both DDT- and PCB-compound have been observed here in young and in all probability rather stationary herring. - It may be mentioned that very high levels have been observed in common porpoise from the south of the Baltic, up to 412 ppm of DDT and

165 ppm of PCB on extractable fat basis in the blubber (values in fresh tissue 251 and 101 ppm respectively). The porpoise subsists to a great degree on herring and sprat. A mixed zoo- and phytoplankton sample from surface water in the central parts of the Bornholm Basin gave values of 56 ppm of DDT and 38 ppm of PCB on extractable fat basis (on fresh weight basis 0.056 and 0.038 ppm respectively). A small number of sampling series of flounder and plaice from the Baltic have all given low values (see table 4), which fact perhaps contradicts a higher accumulation in their nourishment organisms (bottom-living evertebrates).

By its solubility in fat but not in water, DDT- and PCB-compounds can easily be taken up via the surface by, among others, algae and plankton. This implies that pollution may be present in the sea water for a long time without being transported to the bottom but transported horizontally by the current, for example, to the north of the Baltic. In the southern Baltic, especially to the east of Bornholm, there is a very pronounced halocline all through the year (periodically also thermoclines), where dead and living plankton and plankton-eating fish gather. This must to a great degree favour the remaining of the substances in the water environment and also the concentration to the living organisms. Such a permanent halocline exists in the whole Baltic proper up to the Åland Sea but it is less pronounced to the north of the Bornholm Basin. Although from the Åland Sea and further north the water has layers of different salinity, there is no permanent halocline. The water temperature is lower here and the water circulation is good due i.a. to the rich supply of fresh water.

Concentration of persistent compounds, like DDT and PCB, is favoured by the moderate water volume of the Baltic in combination with the limited water exchange over the thresholds in the Belts and the Sound and also by the pollution from the large surrounding land areas, especially along the Baltic proper. The relatively low temperature of the water counteracts the destruction of the compounds by the biological activity (Jensen et al. 1969). The Arkona Basin to the west of Bornholm is a transitional zone, where stratification due to different salinity and temperature is more changing and labile in relation to the somewhat better water circulation of the area, due the nearness to the Danish sounds. In the Kattegat — Skagerak area, the stratification is to an increasing degree surface bound and varying. The rich water exchange with the North Sea and the higher mean temperature here counteracts the concentration of DDT- and PCB-compounds.

References:

Cope, O.B. and Sanders, H.O., 1963. Fish and Wildlife Service. Circular 167:27.

Jensen, S., Johnels, A.G., Olsson, M. and Otterlind, G. 1969. DDT and PCB in marine animals from Swedish waters. - Nature 224: 247-250.

Matsumura, F., Patil, K.C., and Boush, G.M. 1971. DDT metabolized by microorganisms from Lake Michigan. - Nature 230: 325-326.

Olsson, M., Jensen, S., Johnels, A.G., Nucci, B., Westermark, T. 1971. Förekomst av kvicksilver, DDT- och PCB-substanser i gäddor från Stockholms skärgård. - Rapport till statens naturvårdsverk, 31.3.1971. (Mimeogr.)

Otterlind, G. 1961 a. On the migration of the Baltic herring. - ICES, C.M. 1961, No. 121. Mimeogr. (Printed in Swedish in Ostkusten 34:1:15-21, 1962.)

" 1961 b. Swedish cod taggings in the Baltic. - ICES, C.M. 1961, No. 122. Mimeogr. (Printed in Swedish in Ostkusten 34:7:12-17, 1962.)

" 1962. Zoogeographical aspects of the southern Baltic. - ICES, C.M.. 1962, No. 103. Mimeogr.

Westöö, G. and Norén, K. 1971. Klorpesticid- och polyklorbifenylhalter i fisk fångad i svenska vatten eller saluförd i Sverige 1967-70. - Vår Föda 22 (1970):93-146.

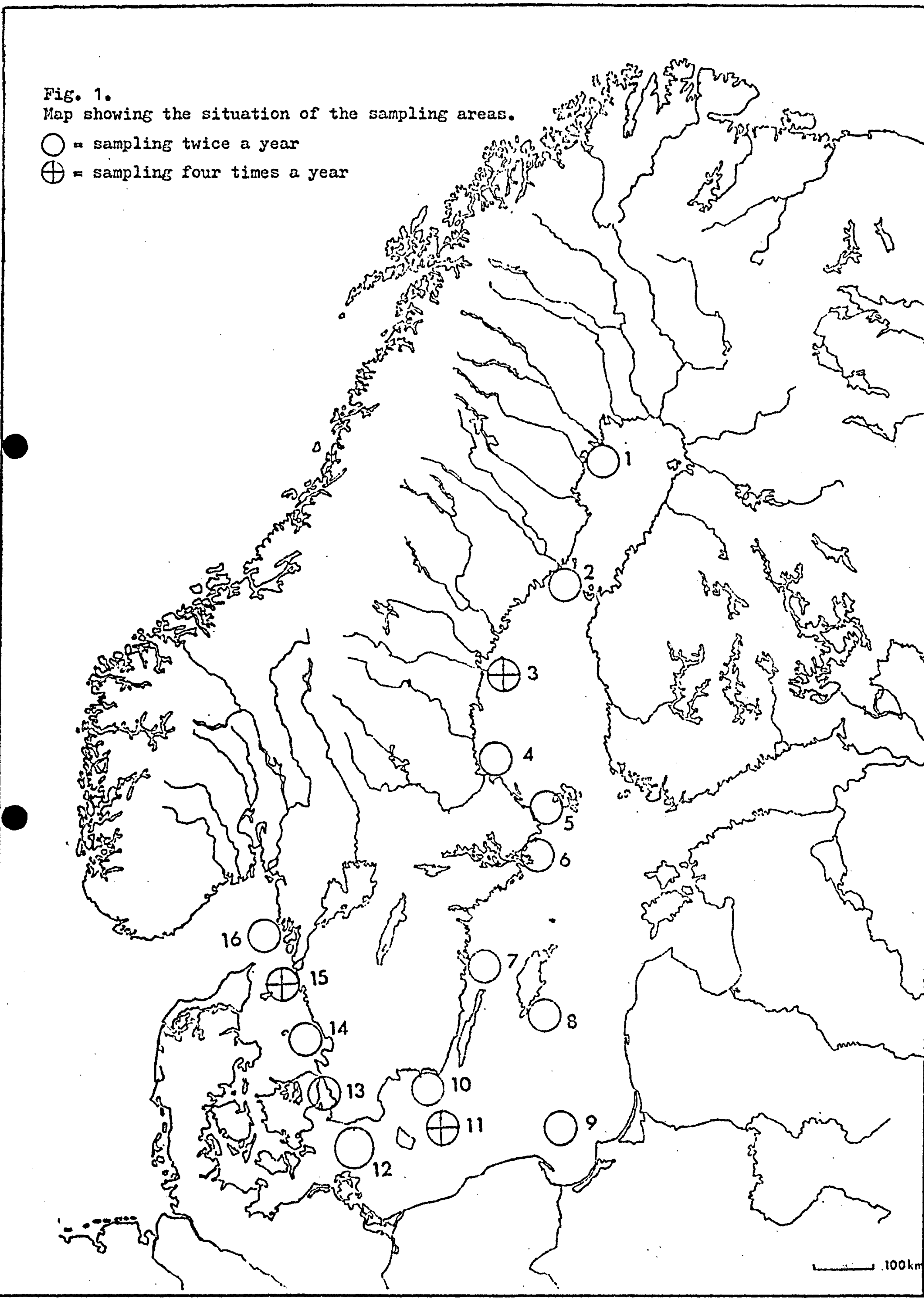

Fig. 1.
Map showing the situation of the sampling areas.

○ = sampling twice a year

⊕ = sampling four times a year

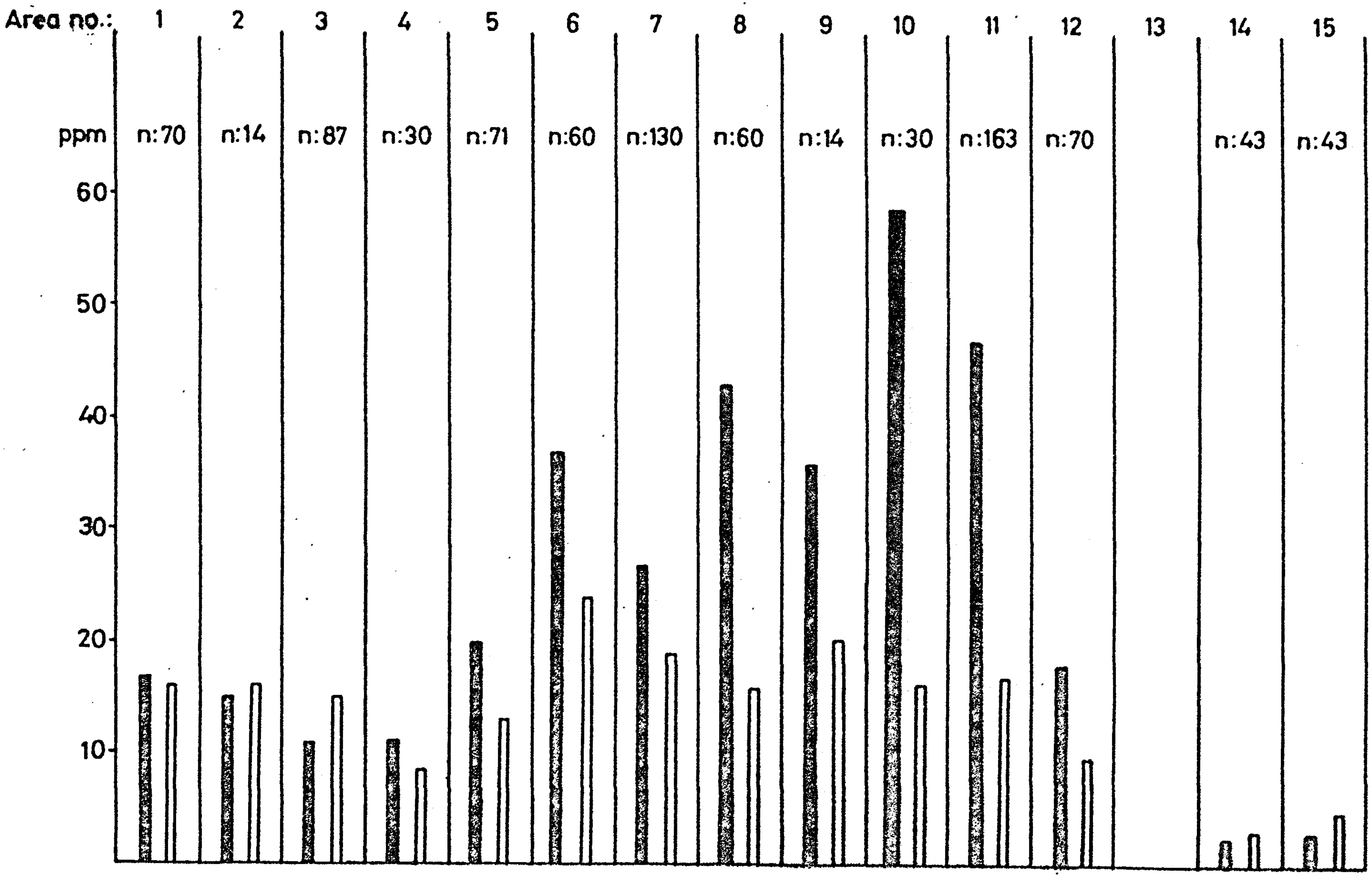

Fig. 2. Mean levels of DDT- and PCB-compounds (black and white columns, respectively) in herring from different areas. Ppm on fat weight basis. n= number of specimens analysed.

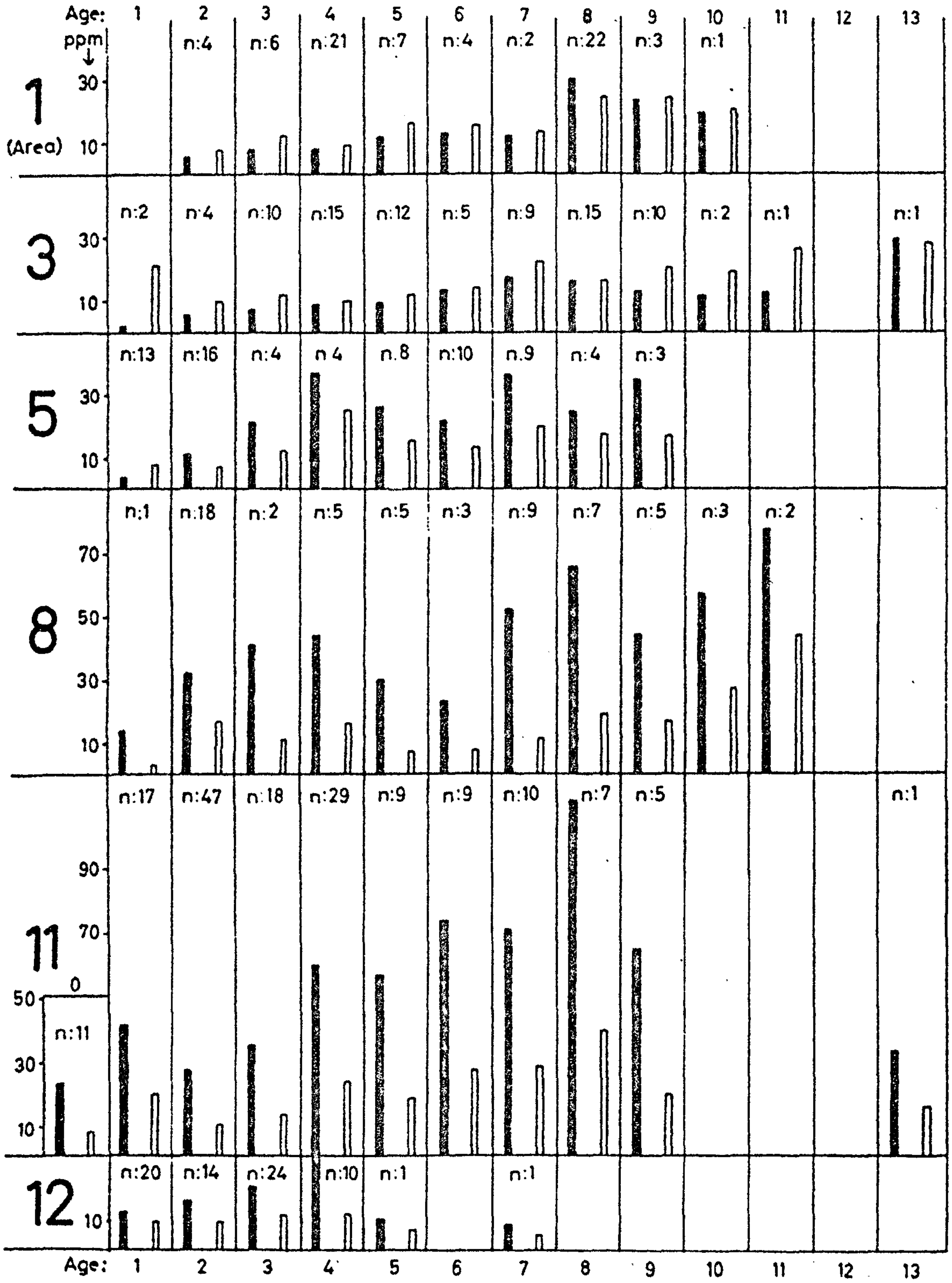

Fig. 3. Mean levels of DDT- and PCB-compounds (black and white columns, respectively) in herring of different ages from the most important sampling areas. Age given in number of winter rings of the scales. Ppm on fat weight basis. n= number of specimens analysed.

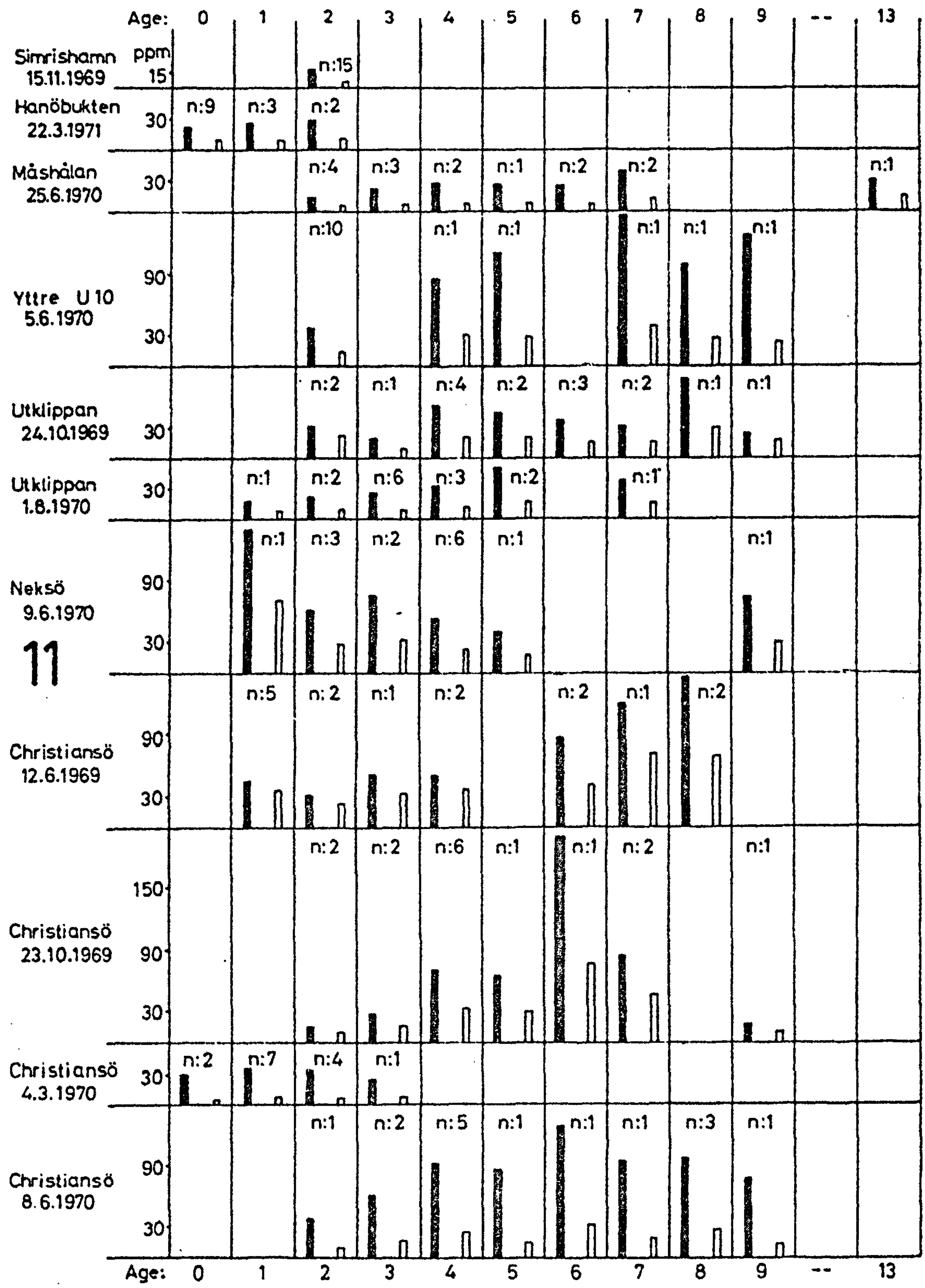

Fig. 4. Mean levels of DDT- and PCB-compounds (black and white columns, respectively) in herring of different ages from different catches in area 11, the Bornholm Basin. Age given in number of winter rings of the scales. Ppm on fat weight basis. n= number of specimens analysed.

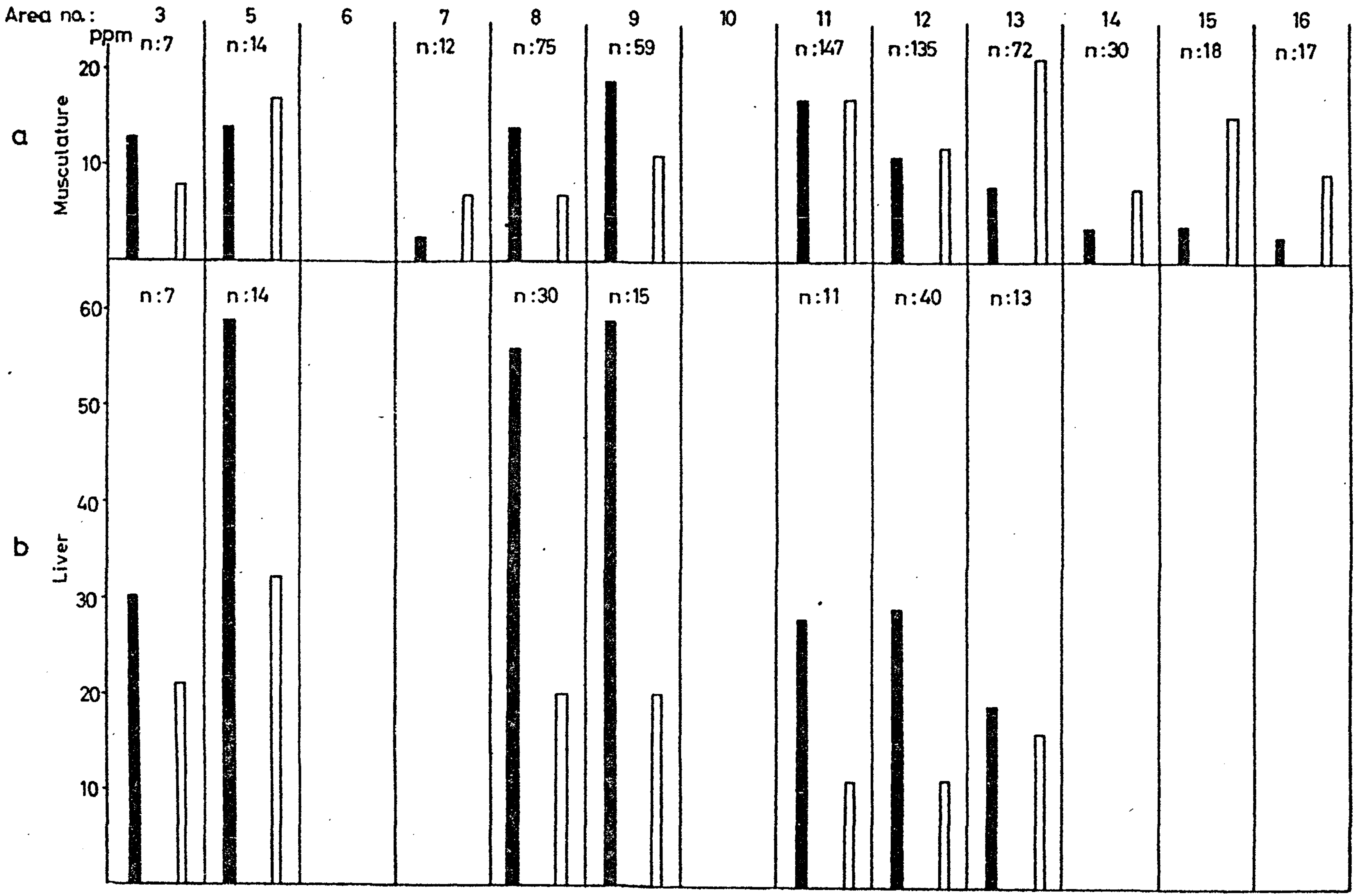

Fig. 5. Mean levels of DDT- and PCB-compounds (black and white columns, respectively) in musculature (a) and liver (b) of cod from different sampling areas. Ppm on fat weight basis. n= number of specimens analysed.

Table 1. Mean levels of DDT- and PCB-compounds and the percentages of DDT and of its metabolites DDE and DDD in samples of herring and cod. Ppm both on fat weight and on fresh weight basis. n = number of specimens analysed.

Herring

Area/Locality	Date	n	Fat weight s.DDT	Fat weight s.PCB	Fresh weight s.DDT	Fresh weight s.PCB	% of s.DDT DDE	% of s.DDT DDD	% of s.DDT DDT
1 Espfjärd S Luleå	24.2.69	10	7,0	6,1	0,52	0,45	45,5	11,7	42,7
Jävrebodarna S Piteå	10.11.69	15	8,1	7,1	0,30	0,27	45,0	14,9	40,1
Espfjärd S Luleå	23.3.70	15	11	16	0,54	0,80	42,3	13,9	43,7
" " "	23.3.70	15	17	20	0,67	0,78	50,8	11,0	38,1
Bondökallarna Piteå skärg	14.7.70	15	37	27	0,57	0,43	55,4	12,1	32,3
2 Täfteå	10.7.69	14	15	16	0,61	0,67	42,6	14,8	42,4
3 6 n.m. S Brämön	26.6.69	15	14	12	0,50	0,40	47,5	12,9	39,5
Brämö kalv	28.7.69	15	11	8,3	0,49	0,37	49,4	13,2	37,3
Eystrasaltbanken	10.11.69	12	7,6	20	0,41	1,00	47,9	13,4	38,5
Brämö kalv	11.11.69	15	8,3	20	0,32	0,78	48,6	14,2	37,0
Åvikebukten NE Sundsvall	6.4.70	15	10	12	0,55	0,67	47,1	15,1	37,7
" " "	6.4.70	15	17	19	0,80	0,89	48,7	13,1	38,0
4 Västra Finngrundsbanken	16.12.70	15	17	12	0,62	0,44	50,2	12,8	36,8
" "	16.12.70	15	5,4	4,5	0,23	0,19	39,8	17,9	42,2
5 Svartklubben	24.6.69	14	29	16	0,58	0,33	39,0	21,7	39,1
Måsten N Svartklubben	1.11.69	13	3,2	8,0	0,12	0,30	33,7	28,5	37,6
" " "	1.11.69	15	37	24	1,4	0,87	38,1	24,5	37,2
Råsten NW "	2.4.70	29	15	7,7	0,51	0,27	45,2	18,1	36,6
6 Torsbyfjärden	21.10.69	15	15	18	0,99	1,20	41,4	28,5	30,0
"	7.5.69	15	17	21	0,80	1,10	34,9	26,4	38,5
"	17.6.70	15	48	25	1,1	0,61	44,1	33,1	22,6
Saxarfjärden	23.6.70	15	67	32	1,0	0,46	42,5	30,5	26,9
7 Gärdsholmen Syrsan	28.2.69	15	20	8,7	0,62	0,27	41,3	15,6	42,9
" "	5.5.69	15	43	14	1,4	0,45	33,4	21,5	45,0
" "	5.5.69	15	24	7,2	0,53	0,15	40,9	13,4	45,6
Näsudden Gamlebyviken	9.5.69	14	24	36	0,34	0,50	54,5	21,4	24,0
Gärdsholmen Syrsan	30.5.69	14	44	32	1,4	1,10	41,5	13,9	44,5

Herring cont.

Area/Locality	Date	n	Fat weight s.DDT	Fat weight s.PCB	Fresh weight s.DDT	Fresh weight s.PCB	% of s.DDT DDE	% of s.DDT DDD	% of s.DDT DDT
7 Bödabukten N Öland	31.10.69	15	37	28	2,0	1,4	42,4	17,7	39,8
Gärdsholmen Syrsan	10.11.69	12	10	7,7	0,51	0,37	45,7	15,4	38,7
NW Ölands N udde	18.11.69	15	22	13	1,0	0,55	37,2	19,4	43,2
Näsudden Gamlebyviken	22.6.70	15	13	24	0,21	0,40	33,8	32,3	33,8
8 ESE När Gotland	5.6.69	15	59	31	1,5[illegible]	0,74	46,7	20,3	32,8
" " "	15.10.69	15	24	6,1	1,0	0,25	39,4	27,0	33,5
" " "	7.4.70	15	37	20	1,2	0,67	35,8	22,7	41,3
" " "	2.6.70	15	51	7,1	1,1	0,15	55,0	19,5	25,4
9 Yttre Gdanskbukten	10.6.69	14	36	20	1,7	0,91	38,8	23,5	37,5
10 Senoren SE Karlskrona	19.5.70	15	56	18	0,89	0,27	31,5	13,5	54,9
"	19.5.70	15	62	14	2,3	0,52	43,9	14,6	41,4
11 ENE Christiansö	12.6.69	15	69	41	2,4	1,4	37,9	20,4	41,6
" "	23.10.69	15	63	29	3,2	1,5	39,6	15,7	44,6
SE Utklippan	24.10.69	15	39	19	2,5	1,2	31,2	18,4	50,3
3' NNE Simrishamn	15.11.69	15	18	4,2	0,82	0,19	31,3	19,0	49,5
ENE Christiansö	4.3.70	15	35	5,9	0,98	0,16	35,3	19,2	45,4
SE Utklippan	5.6.70	15	63	19	1,7	0,50	41,3	21,0	37,6
ENE Christiansö	8.6.70	15	86	21	3,3	0,79	47,3	22,7	29,8
SE Neksö	9.6.70	14	65	28	2,6	1,1	42,6	21,6	35,7
20 n.m. SSE Hanö	25.6.70	15	24	7,1	0,91	0,27	41,0	22,9	35,9
SE Utklippan	1.8.70	15	29	9,6	0,96	0,31	38,5	23,4	37,9
Hanöbukten N55°41'E15°12'	22.3.71	14	23	8,3	0,41	0,15	31,6	17,8	50,5
12 S Trelleborg	5.3.70	15	21	13	0,63	0,43	40,3	19,4	40,2
W Rönne	10.6.70	15	37	14	2,3	0,85	45,2	21,9	32,8
S Adlergrund	26.11.70	10	18	8,7	0,56	0,27	37,6	24,4	37,8
SW Gedser	27.1.71	15	10	8,0	0,30	0,26	31,6	24,1	44,1
S Ystad	8.2.71	15	5,3	4,2	0,48	0,39	35,4	24,3	40,2

Herring cont.

Area/Locality	Date	n	Fat weight s.DDT	Fat weight s.PCB	Fresh weight s.DDT	Fresh weight s.PCB	% of s.DDT DDE	% of s.DDT DDD	DDT
14 SW Falkenberg	17.6.69	15	3,5	5,5	0,16	0,25	29,5	24,7	45,6
8 n.m. Varberg	16.10.69	14	1,7	2,4	0,32	0,45	35,9	19,9	44,1
Hovs hallar	12.11.69	14	1,6	1,9	0,15	0,18	30,1	23,3	46,4
15 SE Grisbådan Gbgs skärg	27.11.69	7	1,4	1,9	0,27	0,37	32,9	25,0	42,0
N om Baggeskär	27.11.69	8	2,3	3,0	0,34	0,44	36,6	21,2	42,1
Vasskären Gbgs skärg	29.11.69	6	2,1	2,5	0,21	0,26	37,0	22,8	40,0
SE Buskär " "	29.11.69	10	1,3	2,9	0,16	0,37	23,8	22,3	53,7
W Hönöhuvud	28.2.69	4	6,3	12	0,10	0,17	30,3	23,9	45,6
W St Pölsan	28.2.69	4	5,2	6,1	0,18	0,18	31,4	21,7	46,7
NW Skagen (16)	18.2.69	4	6,7	12	0,17	0,29	25,0	25,2	50,0

Cod

Area/Locality	Date	n	Fat weight s.DDT	Fat weight s.PCB	Fresh weight s.DDT	Fresh weight s.PCB	% of s.DDT DDE	% of s.DDT DDD	% of s.DDT DDT
3 Åvikebukten NE Sundsvall	4.6.70	7	13	7,9	0,086	0,052	47,9	15,6	36,3
5 SE Understen Ålandshav	17.6.69	14	14	17	0,067	0,081	43,4	16,0	40,4
7 Bödabukten N Öland	20.11.68	12	2,7	6,8	0,024	0,059	30,8	28,4	40,6
8 ESE När	5.6.69	30	11	6,4	0,077	0,047	31,9	17,5	50,4
" "	15.10.69	15	8,9	1,9	0,072	0,016	32,8	22,9	44,2
Rysshålan SSE Gotland	21.10.69	15	20	13	0,12	0,078	34,5	17,0	48,3
" " "	3.6.70	15	20	6,6	0,16	0,051	35,3	22,7	41,8
9 Yttre Gdanskbukten	10.6.69	15	15	11	0,10	0,081	33,5	17,9	48,5
" "	22.10.69	14	16	7,3	0,11	0,049	34,3	17,0	48,6
" "	4.6.70	15	21	16	0,15	0,12	37,5	21,5	40,8
Inre "	17.11.70	15	22	9,9	0,13	0,056	41,4	21,5	36,9
11 ENE Christiansö	12.6.69	15	23	35	0,23	0,39	36,7	14,0	49,1
" "	12.6.69	15	21	12	0,14	0,087	33,3	17,3	49,3
SE Neksö	11.6.69	15	18	23	0,150	0,26	27,5	14,8	57,6
ENE Christiansö	23.10.69	14	5,8	17	0,063	0,19	16,8	19,6	63,5
SE Utklippan	24.10.69	15	6,2	14	0,055	0,12	23,4	21,7	54,8
" "	24.10.69	14	8,8	6,7	0,065	0,052	34,3	14,9	50,6
ENE Christiansö	4.3.70	15	14	10	0,11	0,084	34,2	16,5	49,2
" "	8.6.70	15	22	11	0,14	0,072	34,1	21,8	43,9
SE Neksö	9.6.70	14	18	15	0,13	0,072	31,8	20,5	47,6
" "	9.6.70	15	32	23	0,25	0,180	34,6	17,7	47,6
12 S Trelleborg	16.6.69	15	13	13	0,10	0,11	31,3	19,7	48,9
" "	27.10.69	15	6,1	12	0,056	0,12	27,8	24,2	47,9
" "	5.3.70	15	6,9	13	0,038	0,070	24,4	30,7	44,8
" "	10.6.70	15	12	12	0,085	0,088	26,8	29,4	43,6
W Rönne	10.6.70	15	40	31	0,34	0,27	31,7	21,6	46,5
S Adlergrund	26.11.70	15	6,5	7,8	0,058	0,068	22,7	22,1	55,0
" "	26.11.70	15	5,8	5,3	0,034	0,032	29,1	21,0	49,8
SW Gedser	27.1.71	15	4,7	8,1	0,033	0,058	30,7	27,5	41,6
" "	27.1.71	15	7,3	5,8	0,036	0,029	30,9	24,5	44,5

Cod cont.

Area/Locality	Date	n	Fat weight s.DDT	s.PCB	Fresh weight s.DDT	s.PCB	% of s.DDT DDE	DDD	DDT
13 Klagshamn	3.6.69	13	6,1	13	0,032	0,071	30,2	15,1	54,5
S Ven	16.6.69	14	12	27	0,070	0,17	37,3	17,0	45,4
" "	28.10.69	15	7,8	31	0,047	0,18	35,3	25,4	39,2
Klagshamn	28.10.69	15	4,4	15	0,023	0,080	33,2	18,5	48,2
S Ven	6.3.70	15	8,9	20	0,068	0,15	30,2	24,7	45,0
14 SW Falkenberg	17.6.69	15	5,0	8,5	0,028	0,050	37,6	15,3	46,9
Hovs hallar	12.11.69	15	2,1	6,7	0,011	0,038	30,2	23,1	46,6
15 KA 4 Göteborgs skärg	29.1.69	3	6,9	25	0,039	0,14	26,7	32,9	41,4
Kungsbackafj mynning	17.6.69	15	3,3	13	0,022	0,087	29,3	26,2	44,3
16 Pinnevik Lysekil	16.6.69	12	2,7	9,0	0,014	0,045	25,0	24,7	50,1
Stångholmen Lysekil	16.7.69	5	2,2	10	0,009	0,043	32,3	11,1	56,5

Table 2. Mean levels of DDT- and PCB-compounds in samples of herring of different ages from the same catches. Ppm both on fat weight and on fresh weight basis.

Area	Locality	Date	Number of winter rings	Number in sample	Fat weight		Fresh weight	
					s.DDT	s.PCB	s.DDT	s.PCB
1	Bondökallarna, Piteå skärg.	14.07.70[x]	3	15	14±7,7	15±8,6	0,22±0,083	0,26±0,18
	- " - - " -	14.07.70	8	15	37±14	27±9,2	0,57±0,085	0,43±0,077
4	W Finngrundsbankarna	16.12.70	3	15	5,4±1,5	4,5±1,3	0,23±0,087	0,19±0,054
	- " -	16.12.70	8	15	17±4,2	12±4,2	0,62±0,17	0,44±0,098
5	Svartklubben	01.11.69	1	13	3,2±1,0	8,0±3,0	0,12±0,052	0,30±0,13
	- " -	01.11.69	4-9	15	37±16	24±9,4	1,4±0,62	0,87±0,25
8	SE När, Gotland	25.06.70[x]	2-3	14	18±1,5	7,1±0,73	0,40±0,034	0,16±0,014
	- " - - " -	25.06.70[x]	4-11	12	72±18,4	22±5,16	1,6±0,26	0,51±0,071
10	Senoren, SE Karlskrona	19.05.70	1-2	15	56±19	18±10	0,89±0,27	0,27±0,12
	- " - - " -	19.05.70	4-5	13	62±4,3	14±1,6	2,1±0,17	0,47±0,045
11	SE Simrishamn	24.06.70[x]	2	15	25±9,9	9,3±4,7	0,67±0,16	0,24±0,087
	- " -	24.06.70[x]	4-10	15	45±31	15±12	1,8±0,94	0,61±0,34

[x] New samples not mentioned in table 1.

Table 3. Mean levels of DDT- and PCB-compounds from musculature (fillet) and liver of cod. Both tissues were analysed from the same specimens. Ppm on fat weight basis.

Area	Locality	Date	Number in sample	Musculature s.DDT	Musculature s.PCB	Musculature s.DDT/s.PCB	Liver s.DDT	Liver s.PCB	Liver s.DDT/s.PCB
3	Åvikebukten, Bothnian Sea	04.06.70	7	13	7,9	1,65	30	21	1,43
5	Understen, Åland Sea	17.06.69	14	14	17	0,82	59	32	1,84
8	ESE När, Gotland	05.06.69	15	12	8,0	1,50	47	18	2,61
	SE Gotland	21.10.69	15	20	13	1,54	64	22	2,91
9	Gdansk Bay	17.11.70	15	22	9,9	2,22	59	20	2,95
11	SE Utklippan	24.10.69	11	8,4	5,5	1,53	28	11	2,55
12	S Trelleborg	05.03.70	15	6,9	13	0,53	21	11	1,91
	– " –	16.06.69	11	15	13	1,15	47	18	2,61
	Adlergrund	26.11.70	14	5,8	5,5	1,06	19	4,1	4,63
13	Klagshamn	03.06.69	13	6,1	13	0,47	19	16	1,19

Table 4. Mean levels of DDT- and PCB-compounds and the percentages of DDT and of its metabolites DDE and DDD in samples of various species. Ppm both on fat weight and on fresh weight basis. n = number of specimens analysed.

Species	Area	n	Fat weight s.DDT	Fat weight s.PCB	Fresh weight s.DDT	Fresh weight s.PCB	% of s.DDT DDE	% of s.DDT DDD	DDT
Salmon	1	1	29	10	3,8	1,4	36,0	19,5	44,4
	2	5	47	19	4,3	1,7	38,2	15,8	45,9
	3	1	10	6,9	0,78	0,52	54,3	12,2	33,3
	3	5	15	13	1,7	1,3	50,7	14,9	34,3
	4	4	32	15	1,9	0,84	47,0	15,6	37,3
	7	7	27	10	2,5	0,88	40,1	18,9	40,9
	7	5	26	8,2	4,3	1,3	39,1	18,4	42,4
	7	1	31	6,8	3,7	0,81	37,3	18,1	44,4
	11	5	32	15	4,1	1,9	38	18	44
Whitefish	1	12	7,5	5,1	0,19	0,17	37,3	19,8	42,7
	1	14	6,8	5,8	0,17	0,14	44,4	18,5	37,0
Vendace	1	15	4,7	8,6	0,084	0,15	24,6	24,7	50,5
Sprat	8	15	31	7,1	2,0	0,45	29,4	17,9	52,5
	11	15	18	21	1,2	1,2	17,6	22,9	59,3
	13	15	7,4	3,7	0,31	0,16	26,8	21,5	51,5
	15	15	8,1	9,3	0,28	0,33	24,9	24,5	50,5
Flounder	7	12	8,6	12	0,11	0,15	22,4	24,8	52,7
	8	15	8,7	4,0	0,21	0,090	21,1	27,4	51,4
	11	15	7,9	3,7	0,17	0,075	20,3	26,2	53,4
	12	9	6,4	4,8	0,10	0,085	17,4	26,1	56,4
	12	12	4,5	4,7	0,086	0,070	18,4	29,8	51,7
	13	15	14	27	0,16	0,30	24,3	30,7	44,9
	15	12	16	53	0,19	0,61	19,5	37,5	42,9
Plaice	8	2	7,1	10,2	0,056	0,081	20,5	30,2	49,3
	12	5	5,2	6,1	0,060	0,067	20,8	31,1	47,9
	12	6	5,1	2,9	0,058	0,032	19,0	25,9	55,0
	13	8	4,7	10	0,037	0,078	21,8	32,5	45,5