Polychlorinated Biphenyls (PCBs) and The Precautionary Principle

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Summary

In this paper we examine the problem of PCBs within the PARCOM area with particular reference to the Precautionary Principle. It is argued that sufficient information existed in the 1960s which, if applied as part of a precautionary approach, would have reduced PCB emissions into the marine environment. Instead, the slower 'Permissive' approach has meant that large releases in nominally closed but actually open systems, such as mining, continued into the 1980s. The development of safe substitutes, while technically possible, were similarly delayed, even though when such substitutions have eventually been applied this has involved minimal economic disruption and a commercial opportunity for those companies alert enough to developments within the market.

As a result there has been created a far more serious present and future problem than is generally realized. It is argued here that there is considerable evidence that levels currently present in the marine environment are close too, or even exceed levels that are known to have biological effects; and that the methods used to assess the impact of PCBs have serious shortcomings. Finally, we suggest that all the information was present for this to have been a case-book adoption of the precautionary approach at a very early stage. There was the experience gathered from the parallel problem with persistent pesticides. There were early warnings both from the laboratory and the field of significant adverse effects from PCBs and their generally unpredictable nature. There was even the ability to develop substitutes with minimal economic disruption. Instead, there is concern that, at best, remedial action to prevent further pollution will now be difficult and more expensive than if the Precautionary Principle had been applied, and at worst, we may have already gone beyond the point in certain PARCOM areas where remedial action is possible.

Economic and Industrial Impact

Polychlorinated biphenyls were first produced in bulk in the 1930s, and were used for a wide range of purposes by the late 1960s[1,2]. But increasing awareness during that decade of their impact on people and the environment brought substantial pressure for their phasing out and apparently swift action. This resulted first in their restriction to closed systems in 1972, and then by the voluntary discontinuation of production of PCBs by the Monsanto chemical company in 1977. Production in most, but not all, OECD industrialized countries had ceased by 1985 [3]. As a result, there has been a growing feeling that the PCB problem is now largely under control, and perhaps a need to turn attention to more pressing problems. For instance, in the Ninth PARCOM Report, some questioned whether further research on PCBs was required arguing that 'priority should be given to other areas since inputs of PCBs were declining', and the decision to proceed was indeed put off [4].

A Cautionary Note

The preceding paragraph might be accepted by many as a summary of the development of PCB controls, and decisions such as that taken by PARCOM are understandable in such a light. But a more detailed examination of the history shows that this view at best can only be considered to be partially correct.

For instance, in the Federal Republic of Germany, national utilization declined between 1974–1980, but only from some 3,000 tonnes per annum to a figure somewhat in excess of 2,000 tonnes[5]. Exports from the Republic actually increased, from 3,000 to 5,000 tonnes per annum. There was a shift towards the use of 'weakly chlorinated' PCBs (e.g. a shift of major market share from PCBs with 54% w/w in 1977 to PCBs with 42% w/w in 1980). These were thought to be less persistent, and therefore more environmentally acceptable. But although data is scarce, it now appears that low chlorinated mixtures contain tetrachlorobiphenyls at levels up to 1,000 ppm[6]. These are now thought to be the most persistent and toxic congeners[7]. This aspect is discussed in more detail below.

In theory, the use of PCBs in new 'open system' applications stopped in 1972. But with their wide dispersal in all forms of equipment, peaking in the 1960s, and with a product life of 10-20 years, releases into the environment can be expected to continue throughout the 1990s. While such emissions may not be as dramatic as a single accidental discharge, the widespread nature of the release and the large amounts involved (22,000 to 23,000 tonnes in the Federal Republic alone[8]) cannot be ignored.

The use of PCBs in new 'closed systems', was permitted until 1985. In some ways 'closed' is not an accurate description, as accidents, improper maintenance and improper disposal can all result in release of PCBs into the environment. However, these considerations pale into insignificance compared to the gross mis-classification of the use of PCBs in mining hydraulic equipment as a closed application. In fact within the FRG, some 10,000 tonnes of PCBs, mostly highly chlorinated, have been released into mine workings, annual consumption of which had risen to 1,600 tonnes by 1980 (62% of which was imported from France), when it accounted for 70% of national consumption of all PCBs. The Precautionary Principle was not much in evidence here, and their are few statistic on the contamination of the wider environment through pit water extraction, ventilation and mine output.

The greatest bulk (some 30,000 tonnes in the FRG) of PCBs is in large condensers and transformers. Their long product life (20 to 50 years) and simple function has resulted in few leaks from operational difficulties. But throughout the 1990s and into the twenty-first century, the safe disposal of large quantities of PCBs from these will become a significant issue that will have to be tackled if major problems are to be avoided.

There is reason to believe that the situation is not substantially different in many other PARCOM countries. Worldwide, over half of the total PCB production of between one and two million tonnes is thought to have already entered dumps and landfills[9]. Clearly, even if production ceases, (in 1987 France and Spain were still thought to be producing some 8,000 tonnes per annum[10]) we are left with significant present and future problems. If these are to be minimized, in so far as this is possible, organizations such as PARCOM must base their approach on the precautionary principle and should be preparing now for preventative action, and avoid the temptation to continue to rely on a combination of monitoring and attempted remedial action after local problems become apparent.

The Technology and Economics of PCB Substitution and Elimination

Once the need for substitutes was apparent, these were developed without any great difficulties for the range of relatively minor applications such as in adhesives, solvents, printing inks and the like. The development of substitutes for one major use, as a dielectric, had been largely resolved by the start of the 1980s, and PCB-free substitutes for mining were also well under way.

Moreover, the costs of PCB substitution has been far from crippling. In what is usually considered the most difficult case, the mining industry, it was expected that substitutes would cost between 10 and 75% more than the PCBs they replaced. In comparison to overall operating costs and sales, this effect is very small. More widely, the structure of the type of companies that produced PCBs is such that they typically represented only a minor part of their operations. For example, in a company such as Bayer, PCBs represented under one thousandth of annual world sales. Furthermore, they developed silicone oil substitutes for PCBs, providing new market opportunities. Similarly, Monsanto, the major producer in OECD countries, were able to give up production voluntarily. Put this context, PCBs are just one more twist in the ever changing markets that are an expected part of commercial life, presenting opportunities for far-sighted companies at the expense of those with sleepy management.

These substitutions were not the result of any great leap in chemistry or materials science between the 1960s when the problems first became apparent, and the 1980s when many of the substitutes were actually developed; simply the result of putting in the basic research effort to meet a need. Had there have been a full-bodied precautionary approach based on the scientific advise then available (see later), we believe that the present and future problems in the marine environment, documented in the next section, would have been substantially ameliorated, and the clean up costs would have been very much less. Application of the precautionary principle is still essential if the impact of the remaining stocks is to be minimized.

The Continuing Marine Impact of PCBs

The full significance of PCBs in the environment began to be realized in the mid 1960s, with their detection, as a significant contaminant, during the assessment of the build-up of pesticides in wildlife. As early as 1972 it was known that PCBs were among the most widespread of contaminants, found even in Antarctica[11]. It is widely understood that marine systems are amongst the most seriously perturbed, with levels in different areas ranging between 1 and 10 ng/l, and PCBs are in fact more persistent than their close chemical relatives, the organochlorine pesticides and their metabolites. Coastal seas and estuaries have higher levels as a result of their proximity to land based pollution, and levels of the order of 100 ng/l (0.1 μg/l) are recorded in the lower courses of the Elbe, Weser and Ems, which are probably typical of other industrialized rivers in the PARCOM area. The phenomenon of atmospheric transport of PCBs from land to sea has been demonstrated even for deep ocean areas such as the Sargasso, and annual aeolian fluxes to the surface are respectively some twenty times and eighty times greater in the Mediterranean and Baltic Seas[12]. The return flux from the marine to the terrestrial environment, a situation with parallels with the unanticipated return to land of radionuclides from radioactive discharges (see other annex), is now also being examined[13].

The slow move towards a ban on PCB in new applications in 1985 has not been the result of a gradual accumulation of evidence that lead to the suspicion of harmful effects on wildlife. Instead it has been known since at least 1969 that PCBs are a major and unpredictable problem, when an extremely bad incident resulted in the deaths of at least 17,000 Guillemots (*Uria aalge*) sea-birds in the Irish Sea – probably in excess of 5% of the British population. These dead birds were found to contain, on average, twice the level of PCBs than those still living. The scientists involved in examining this incident concluded that the most likely sequence of events was that accumulated PCBs in the fat reserves of the birds were mobilized in lethal quantities during a period of adverse weather and food shortages, with mortality perhaps exacerbated by increased vulnerability to disease[14,15].

By the mid-seventies it had been established that PCBs could inhibit the growth of marine algae at concentrations of the order of 10 µg/l; that PCBs accumulated in shellfish such as mussels[16], cockles and tellins[17]; and that juvenile shrimps exposed to 5 µg/l suffered 72% mortality after 20 days, while juvenile blue crabs suffered a 5% mortality rate[18]. Even more worrying, long term exposure to PCBs, at concentrations above 0.1 µg/l, has since been demonstrated to have an adverse effect in mixed cultures of plankton and invertebrates, leading to population changes and a reduction in species diversity[19], and the inhibition of growth in marine algae has now been documented at levels as low as 50 ng/l (i.e. 0.00005 mg/l !)[20].

Moving to the vertebrates, it is now known that young fish mortality may increase if the parents and eggs have been exposed to levels of 0.1 µg/l and malformation and mortality has been correlated with PCB residues of 0.5 to 3 mg/kg wet weight in spawn[21]. Moreover, the pattern can be very complex even within a single species. For instance, after 10 days exposure, LD_{50}s for different cohorts of rainbow trout *Salmo gairdneri*, resulted from water concentrations ranging between 38 µg/l to 326 µg/l, and this in turn fell to between only 6.4 and 49µg/l when the exposure period was extended to 20 days[22]. Under natural circumstances, PCB exposures will be perhaps be one to two orders of magnitude less in the marine environment, but the exposure will be continual. Again, there are few grounds for comfort.

For marine mammals and sea-birds a further hundredfold increase has been recorded, with levels of between 50 mg/kg and 1g/kg found in fatty tissues[23]. One drastic effect of PCBs on birds has already been discussed. Elsewhere, high concentrations of DDE and PCBs were found in German sea-birds, particularly in gulls, and the higher levels found in older individuals were thought likely to lead to a reduction in life span[24]. Reproductive disturbances in Baltic seals were found to be associated with elevated levels of PCB and DDT residues, with similar problems in the west and east Waddensea areas[25]. Indeed, the possibility that PCBs might be responsible for seal population decline was raised as early as 1976[26,27] and reproductive depression has been demonstrated for seals fed on fish caught in the Waddensea[28]. There is evidence that relates the structure of PCB congeners with their metabolism by seals, where the most persistent were found to also be the most toxic[29]. These coplanar PCBs – the tetrachlorobiphenyls – are in fact present in a wide variety of marine animals. They can be regarded as functional stereoisomers of the highly toxic tetrachlorobenzodioxins (dioxins) and have very disturbing implications for marine ecosystems, although their detection in environmental samples present considerable analytical difficulties[30]. These factors, within the background of a still developing knowledge of the adverse effects of PCBs (note the reference publication dates), clearly illustrate the need for a precautionary approach.

The levels found within organisms reflect significant bioaccumulation, of the order of 10,000 to 1,000,000 times background level for plankton, invertebrates and some fish, with perhaps a further hundredfold bioaccumulation for sea-birds and mammals; thus explaining why such low background levels have such significant effects. This lead the West German Federal Health Office

(BGA) and the Federal Environmental Agency (UBA) to suggest that water concentrations above 0.01 μg/l would be detrimental for fish species bioaccumulating PCBs by 100,000 fold. In unfavorable circumstances, mammals feeding on these fish could arrive at damaging levels of 10 mg/kg from a water body with an average concentration of only 0.001 μg/l[31].

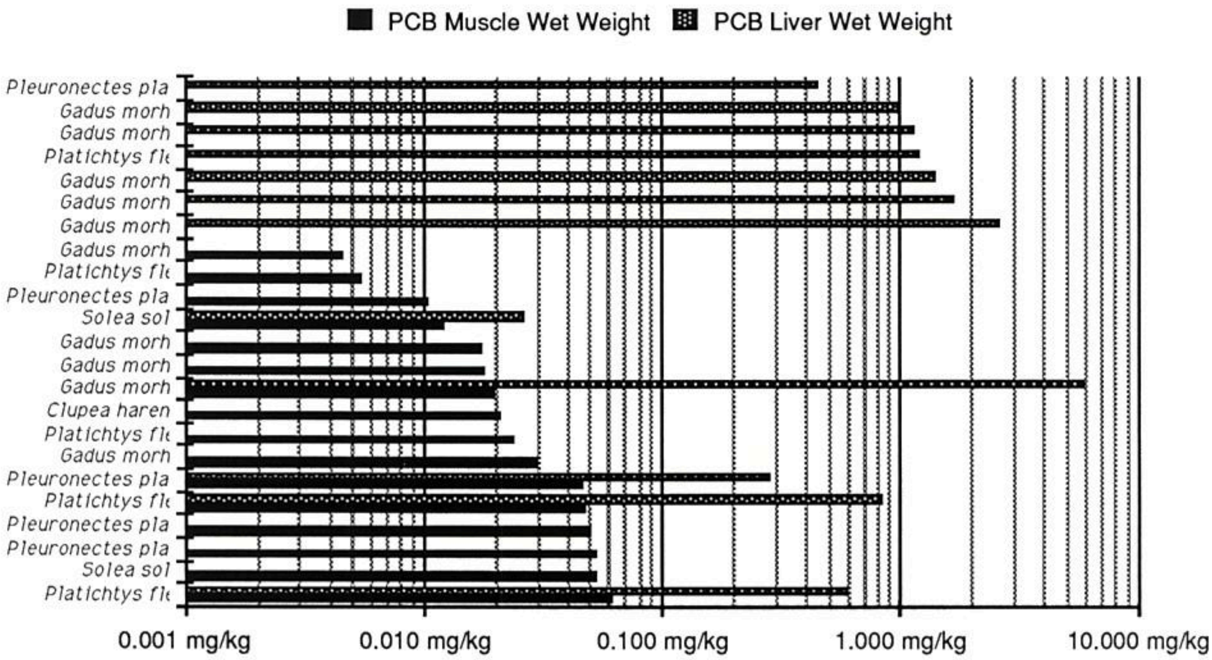
They concluded therefore that, if one was to determine a level for PCBs in the marine environment on the basis of ecology and physiology, this would have to be of the order of 1 ng/l (0.001 μg/l). Ideally, of course, there should be far more accessible data on the impact of these levels on marine life. While, as with other contaminants, there is a considerable body of information within the 'grey literature', this is often not readily available.

Given all these problems, the BGA and UBS's suggestion that as a general principle, habitats should be considered to be 'at risk' when ambient concentrations are within one order of magnitude of those where lethal effects have been observed under laboratory conditions appears entirely reasonable. Below this they suggest a second zone, ranging from one to two orders of magnitude below observed laboratory lethal effects which might be classified as giving 'cause for concern'. This strikes a chord with the work of other environmental scientists. For instance, Konemann[32] considers that even if laboratory testing allows a reasonable estimate of a 'no effect' level for a single chemical, in the natural environment this is compromised by the many variables that now impinge on the organism, and the synergistic and antagonistic effects of multiple pollutants, notwithstanding the gradual development of laboratory multi-[chemical] species toxicity testing systems. PCBs produced to technical standards may actually contain as many as 100 of the 209 theoretically possible PCB congeners. The conclusion from Konemann's work was also that a safety margin must be allowed between 'no effect' concentrations in the laboratory and 'safe' concentrations in the natural environment.

However, the FRG report regarded their 1 ng/l safe margin for PCBs as technologically impossible given the present situation, particularly when those PCBs already in equipment, in waste-tips or in mine workings are taken into account, which it will be difficult to have any control. Instead they suggest that can now be done is to attempt to minimize inputs, presumably with all those involved being aware of the background and urgency required, and that for once, 'minimized' must mean exactly that. That it can even be suggested that we may have arrived at such a situation can hardly be considered reassuring.

PCB levels in the PARCOM area

We now turn to compare these formal assessments with the results that have been gathered in the PARCOM area. The entire dataset for the PCB levels in fish included in the 1986 PARCOM Eighth Report, collected as part of the 1984 Joint Monitoring Programme, is shown in the figure opposite.



PCB contaminants in fish examined as part of the 1984 Joint Monitoring Programme, measured in mg/kg wet weight. The top part of the graph shows data where only the liver concentrations (grey bars) were known, the bottom part for those fish where muscle concentrations were known. For some of this second category, liver PCB concentrations were also available. The two series are ranked in order of increasing PCB concentrations. Note the logarithmic scale. The species were Cod *Gadus morhua*, Flounder *Platichtys flesus*, herring *Clupea harengus*, and Sole *Solea solea* and *S. vulgaris* .

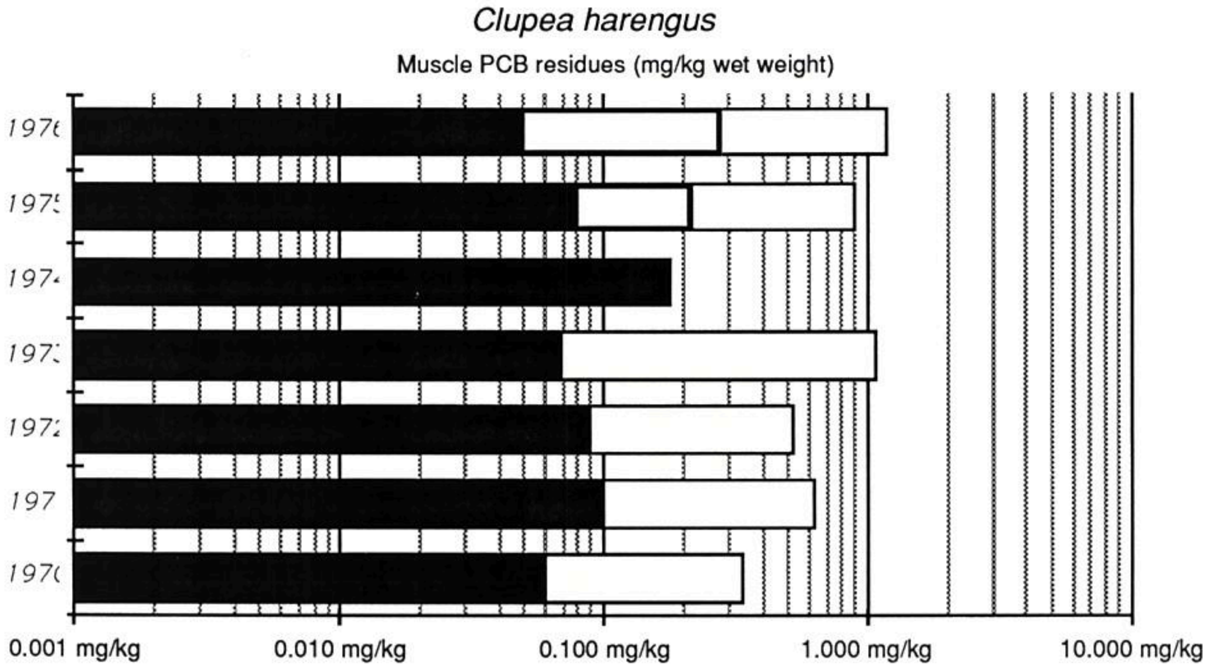
Source: Table 5, Annex 18, Eighth Annual Report on the Activities of the Paris Commission

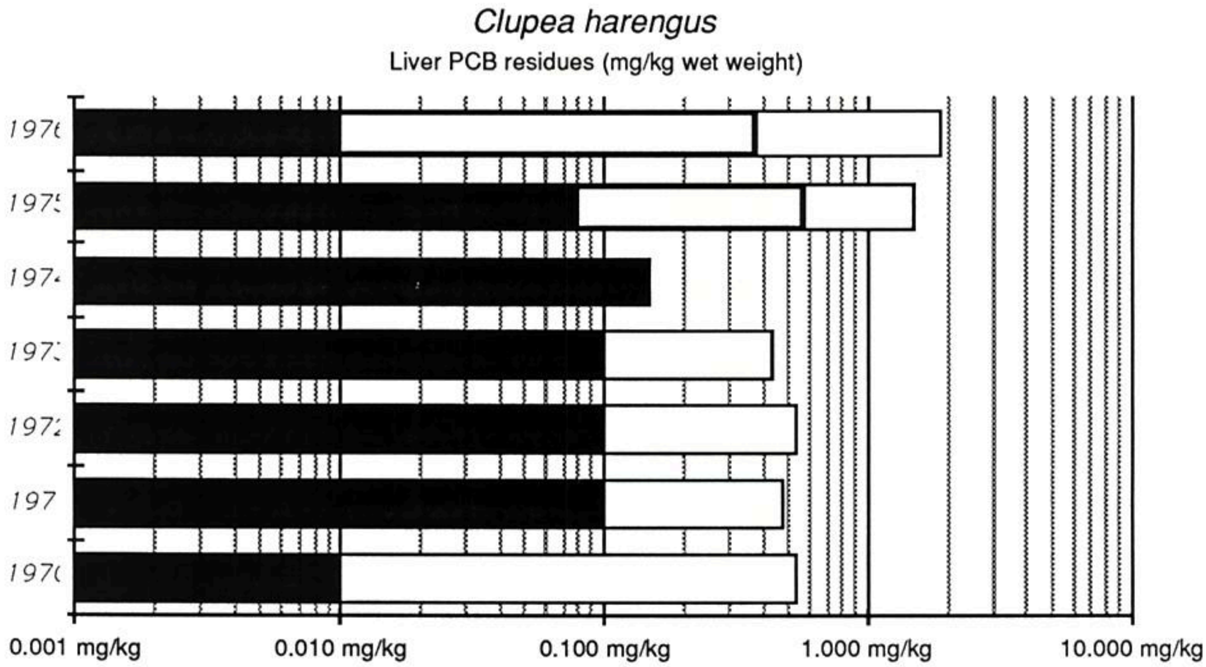
The first, and clearest point to make is that, using the 1 mg/kg level as a standard point at which lethal effects are likely to be observed in the laboratory, and the system of precautionary zoning discussed above, then the levels occurring in these fish populations are too high for safety. For simplicity of analysis, if we examine only those fish where muscle samples were taken, and make no allowance for the contribution to the body burden from the liver, the fish with the highest levels here are certainly nudging the 'at risk' zone, one tenth of the level at which lethal effects are observed, and the majority of fish are well within the 'concern' zone. Indeed, if we acknowledge that some malformations and mortality occurs at 0.5 mg/kg, then this puts half of the fish sampled in the 'at risk' zone. Within this group of fifteen samples it is possible to examine whether the levels of PCBs are statistically higher in the muscles of the benthic (bottom dwelling) species (*Platichtys flesus, Pleuronectes platessa and Solea solea*). A Mann-Whitney test gives a value for U of 10.5; [$n_1 = 6$, $n_2 = 9$], failing at the usual 5% level for a two tailed test (U = 10), but comfortably within that for a 10% probability (U = 12). In other words, the benthic species show a strong tendency to have higher levels of PCBs than the other species, albeit one that is not quite statistically significant.

But perhaps the most significant points come not from the analysis of this data, but from what is missing. While it is understandable that given the limited resources available it may be necessary to determine the species examined on general survey criteria, not that of PCBs alone, it has to be said that the species selection is not an ideal one so far as providing a warning of significant effects from PCB contamination. Because of PCBs high affinity for lipids, we suspected that oily fish such as the herring *Clupea harengus* and mackerel, *Scomber scombrus* may be more sensitive indicators, amongst the fish, of wider effects. Herring shed their eggs close inshore, and are preyed upon by numerous predators, including other fish, sea-birds and dolphins[33]. Mackerel occupy a higher place in the food-web, is a predator of other fish, with herring recorded as favoured prey species, and are slow growing and long-lived (up to 20 years)[34]. These additional factors might also be significant in relation to PCBs.

The data set we examined for these two species were those compiled by the UK Ministry for Agriculture, Forestry and Fisheries (MAFF)[35]. The results are not as detailed as one would wish; sample sizes are either small or very small, and they simply document results from 'fish landed from UK marine waters. However, enough information is present to give cause for concern [see opposite and next page]. For herring, throughout the period of sampling, typical muscle levels of PCB residues were well within the area considered 'at risk' by the Federal German study, and in two years the maximum levels recorded were actually above 1 mg/kg. Levels recorded by MAFF were typically an order of magnitude greater that those recorded for the other species in the PARCOM Eighth Report. If anything, the situation is even more worrying for mackerel, because even the minimum levels recorded for this species were usually either on or above the 'at risk' levels. If the contribution from the liver is taken into account, the overall body load must be higher still. And again, it has to be recalled that lethal effects and malformation has been recorded in fish at levels as low as 0.5 mg/kg, and that adverse sub-lethal physiological and behavioural effects most certainly cannot be ruled out at the levels recorded. Nor should it be forgotten that these were selected from fish caught for human consumption; although herring and mackerel are wide ranging, it is possible that higher levels would have been recorded if the samples had been taken from areas known to be contaminated.

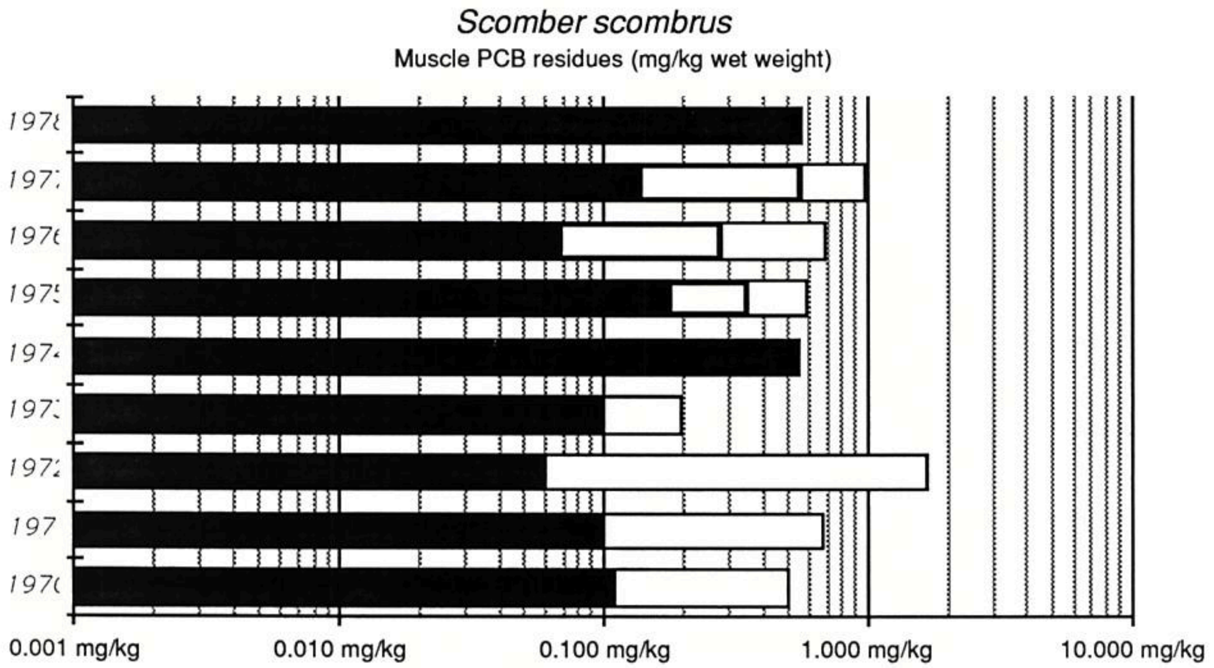
It may well be that other species, such as tuna, which are in same family (Scombridae) as mackerel are high level predators, and which have a high metabolic rate, will also be found to have high levels of PCBs if they are examined in sufficient detail.

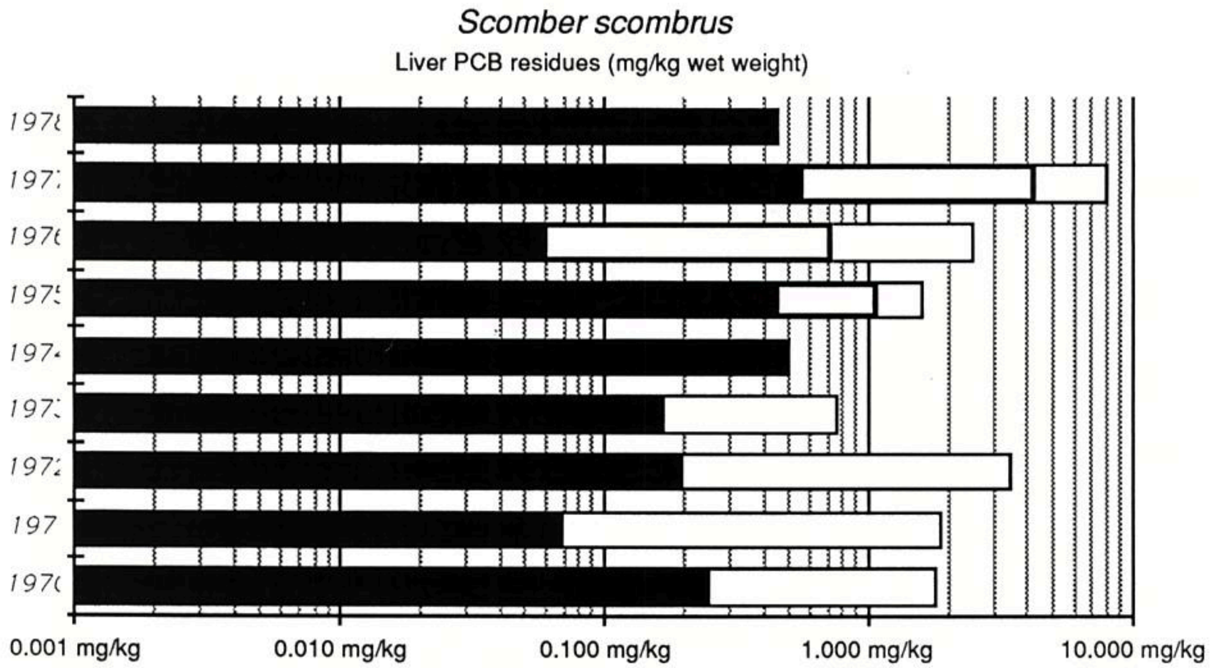




Levels of PCB residues in herring, *Clupea harengus,* landed from UK marine waters, in muscle (top) and liver, from 1970-1976. The black bar represents the minimum level recorded, the thick bordered bar the mean, (where this was available), the thin bordered bar the maximum level recorded. The sample sizes are not recorded for 1970-1973; after then the sample sizes were [year: muscle: liver] 1974:1:1, 1975:7:3, 1976:6:6. Note the log scale. The 'at risk' zone discussed in the text extends down to 0.1 mg/kg, the cause for concern zone down to 0.01 mg/kg.

Source: Ministry of Agriculture, Fisheries and Food (1983) Polychlorinated biphenyl (PCB) residues in food and human tissues; The Thirteenth report of the Steering Group on Food Surveillance. *Table 5*





Levels of PCB residues in mackerel, *Scomber scombrus,* landed from UK marine waters, in muscle (top) and liver, from 1970-1978. The black bar represents the minimum level recorded, the thick bordered bar the mean, (where available) and the thin bordered bar the maximum level recorded. The sample sizes are not recorded for 1970-1973; after then the sample sizes were [year: muscle: liver] 1974:1:1, 1975:5:5, 1976:7:7, 1977:2:2, 1978:1:1. Note the log scale. The 'at risk' zone discussed in the text extends down to 0.1 mg/kg, the 'cause for concern' zone down to 0.01 mg/kg.

Source: Ministry of Agriculture, Fisheries and Food (1983) Polychlorinated biphenyl (PCB) residues in food and human tissues; The Thirteenth report of the Steering Group on Food Surveillance. *Table 5*

We consider that there are several biological lessons to be learnt from this. First, the PCB problem cannot be considered to be largely under control; levels considered acceptable by PARCOM appear only loosely related to the scientific knowledge; a point that certainly requires an explanation, and a reconsideration of the 1 mg/kg level. Secondly, we view with considerable concern that evidence that there could be significant problems, even with important economic species such as mackerel, should be passed over without comment, apparently unnoticed. But we believe that there is also a general problem with the selection of monitored species, which fails to select sufficient species on ecological and physiological considerations (such as the microscopic meiofauna of estuarine and coastal mud[36, 37, 38, 39]), a point that was at least partially made in the Ninth PARCOM Report[40].

More generally, it may also be possible for PARCOM to improve the collection, analysis and publication of statistics. Certainly the presentation of conclusions from the 1985 Baseline Study of Contaminants in Fish and Shellfish (Annex 18, PARCOM Ninth Report) represents a welcome improvement, in which herring was included, although mackerel was not – although the tables on PCB concentrations were omitted from the report. But the inclusion of summary statistics such as the number of samples, the standard deviation and the range are very welcome (Annex 18, Tables 2 to 10), although the absence of individual data (as in the Ninth Report) makes later reassessment more difficult. Similarly, while it is understandable that pooling samples of fish for analysis may be an efficient way of examining the risk to human health, it loses valuable information when assessing the situation in the marine environment. A chain of evidence is only as strong as its weakest link. If the ecological sampling procedure is poor, then no matter how good the chemistry, it will still produce unreliable results. We therefore hope, in the wake of analytic improvements, that PARCOM will also make the ecological methods considerably more rigorous[41].

Discussion; The Precautionary Principle

Earlier in this paper we referred to the first significant case of PCB related mortality in the PARCOM area – the large scale death of guillemots in the Irish Sea in 1969. N. W. Moore, who from 1960 to 1974 was in charge of the UK Nature Conservancy's Toxic Chemicals and Wildlife Section, the statutory body responsible for investigating this incident, recently wrote; –

> 'Then, autumn gales, possibly exacerbated by a shortage of fish in the area, caused starvation and hence the mobilization of fat reserves, which released PCBs into the blood streams of the Guillemots and killed them.'
>
> 'Many of us had little doubt that the role of PCBs had been significant and that we should publicize the event as yet another example of a persistent fat-soluble substance providing an actual or

> potential threat to wildlife. The "official" line was more cautious: it was felt that since we could not prove that PCBs had had a significant effect on the Guillemots it was scaremongering to suggest that PCBs might be involved. There were parallels with pesticides: "scientific purity" was used as an excuse not to take the action demanded by a commonsense appraisal of the total situation. Fortunately in this case commonsense prevailed amongst those who could do most about it – the manufacturers of PCBs.'[42]

Some twenty years later, we feel compelled to ask whether anything has changed. The evidence of potential deleterious effects grows ever stronger yet still these materials are dumped to the environment. It is estimated that the PCBs dumped in UK landfills just from the small capacitors typical of domestic applications amount to some 600 tonnes per annum [43].

The control of PCBs should surely have been a text book case of the application of the Precautionary Principle. There were substantial suspicions about the possible implications of PCBs in the mid 1960s, in the wake of experience gained with their chemical relatives, the DDT family. A range of evidence was available by the mid 1970s of significant adverse effects of PCBs on organisms at all levels of the marine community. The dubious distinction between open and closed uses of PCBs allowed large volume production of PCBs into the 1980s with little thought about how the PCBs produced are to be disposed of at the end of their working life. There was the even more dubious classification of highly chlorinated PCBs in mining as a closed system. Yet when action within the framework of the 'Permissive' Principle finally required the development of alternatives for closed system PCBs, this was done with few technical difficulties, and with little significant economic impact. Indeed, the issue of PCB substitution has hardly surfaced on the public agenda.

The last sentence of the quote above referred to the Monsanto chemical company's unilateral action in 1977. The situation is actually far more complex that the quote suggests, as described in this paper. However, we would make the comment that a if a company can react on the basis of reasonable evidence, yet fail to be backed by action in national and international bodies, they have every right to feel aggrieved at others who attempt to profit at their expense. Such a slow response can surely only harm the future case for expecting companies to take responsible actions in other areas of pollution control.

Instead, action over PCBs is still largely reactive, waiting, just as in 1969, for adverse effects to be demonstrated rather than anticipating them. Levels of PCBs that are considered acceptable in marine organisms, and the limited selection of species that are examined, is still largely based on their possible impact on people who may eat them, rather than on selecting them on their value as indicator species on ecological and physiological grounds. As a result, the threshold value for fish widely accepted in the PARCOM area, of 1 mg/kg, is set at a level that is known to cause fish mortality, and is certainly one order of magnitude too high, and probably two orders of magnitude too high, for a what could be considered a precautionary approach based on the available scientific evidence. We are also extremely concerned that even when results within the limited sampling framework have show high levels of PCBs, such as those for mackerel in British waters, that this had not been followed up nationally and internationally with the urgency such a situation requires. Furthermore, we strongly suspect that the examples of PCB toxicity and sub-lethal effects now emerging in sea-birds and mammals are merely symptomatic of a far wider problem. We see all of these aspects as reflecting the need for a far greater level of commitment to the monitoring for possible adverse effects of man-made discharges on the marine environment.

Instead, we are concerned that, at best, remedial action will now be more difficult and more expensive than if the Precautionary Principle had been applied. We are worried that present levels may already be having significant adverse effects. With the large reservoir of PCBs still in existence, much of it highly dispersed, we do not find the suggestion that the problem is largely solved a reassuring one. Why is it, twenty years on from the mass death of guillemots in the Irish Sea, that luck still remains a substantial element of PCB pollution control in the PARCOM area?

References

[1] Royal Commission on Environmental Pollution (1985) *Eleventh Report: Managing Waste: The Duty of Care* pp. 7–10 and 90–4. HMSO, London.

[2] Murdoch, W.W. (1975) *Environment: Resources, Pollution and Society.* p. 286 Sinauer Associates, Sunderland, Massachusetts.

[3] *op. cit.* 1

[4] Paris Commission (1987) *Ninth Annual Report of the Paris Commission,* p. 28. PARCOM, Paris.

[5] Lorenz, H. and Neumeier, G. (1983) Polychlorierte Biphenyle (PCB): *Ein gemeinsamer Bericht des Bundesgesundheitsamtes und des Umweldbundesamtes.* pp. 25-6 (English version) bga-Schriften 4/1983. This paper is a summary of the detailed joint report of the Federal Health Office and the Federal Environmental Agency.

[6] Kannan, N., Tanabe, S. Wakimoto, T. and Tatsukawa, R. (1987) *A simple method for determining non-ortho substituted PCBs in Kanechlors, Aroclors and environmental samples.* Chemosphere **16,** p. 1631.

[7] Tanabe, S., Kannan, N. Subramanain, A. N., Watanabe, S. and Tatsukawa, R. (1987) *Highly toxic coplanar PCBs: Occurrence, source, persistency and toxic implications to wildlife and humans.* Environmental Pollution **42,** pp. 147 -160.

[8] *op. cit.* 5

[9] Anon. (1983) *Polychlorinated biphenyl (PCB) residues in food and human tissues; The Thirteenth report of the Steering Group on Food Surveillance.* p. 5. HMSO, London.

[10] Ayres, D. C. (1987) *Organochlorine waste disposal: cremation or burial?* Chemy. Brit. January 1987, pp. 41-3.

[11] Jensen, S. (1972) *The PCB Story.* Ambio 1, pp. 123-31.

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[12] Knap, A. H. , Binkley, K. and Deuser, W. G. (1986) *Synthetic organic chemicals in the deep Sargasso Sea.* Nature (Lond.) **319**, pp. 572-574.

[13] Larsson, P. and Okla, L. (1987) *An attempt to measure the flow of chlorinated hydrocarbons such as PCBs from water to air in the field.* Environmental Pollution **44**, pp. 219-225.

[14] Clark, R. B. (1987)*The Waters around the British Isle: Their Conflicting Uses.* p. 230-1 Claredon Press, Oxford

[15] Moore, N. W. (1987) *The Bird of Time,* pp. 193-99. Cambridge University Press, Cambridge.

[16] Risebrough, R.W., Lappe, B.W. de and Schmidt, T.T. (1976) *Bioaccumulation factors of chlorinated hydrocarbons between mussels and seawater.* Marine Pollution Bulletin **7**, pp. 225-8.

[17] Langston, W. J. (1978) *Accumulation of polychlorinated biphenyls in the Cockle* Cerastoderma edule *and the tellin* Macoma balthica. Marine Biology **45**, pp. 265-72.

[18] ibid, p. 287-8.

[19] *op. cit.* 5, p. 26.

[20] Michaels, R. A. Rowland, R. G. and Wurster, C. F. (1982) *Polychlorinated biphenyls (PCB) inhibit photosynthesis per cell in the marine diatom* Thalassiosira pseudonana. Environmental Pollution (Series A) **27**, pp. 9-14.

[21] *op. cit* 5, pp. 25–6.

[22] United Nations Environmental Programme (1982) *The Health of the Oceans; UNEP Regional Seas Reports and Studies No. 16,* p. 42. UNEP, Geneva. Cited in International Institute for Environment and Development/World Resources (1987)*World Resources 1987,* p. 127. Basic Books, New York.

[23] *ibid.*

[24] *ibid.*

[25] UK Department of the Environment (1987) Second International Conference of the Protection of the North Sea *Quality Status of the North Sea.* A Report by the Scientific and Technical Working Group. pp. 49-50. HMSO, London.

[26] Helle, E., Olsson, M. and Jensen, S. (1976) *DDT and PCB levels and reproduction in ringed seals from the Bothnian Bay.* Ambio 5, pp. 188-9.

[27] Helle, E. , Olsson, M. and Jensen, S. (1976) *PCB levels correlated with pathological changes in seal uteri.* Ambio 5, pp. 261-3.

[28] Reijnders, P. J. H. (1986) *Reproductive failure in common seals feeding on fish in polluted coastal waters.* Nature (London) 324 , 456-7.

[29] Boon, J. P., Reijnders, P. J. H., Dols, J., Wensvoort, P. and Hillebrand, M. T. J. (1987) *The kinetics of individual polychlorinated biphenyl congeners in female harbour seals* Phoca vitulina, *with evidence of structurally related metabolism.* Aquatic Toxicology **10**, pp. 307-24.

[30] Tanabe, S., Kannan, N. Subramanain, A. N., Watanabe, S. and Tatsukawa, R. (1987) *Highly toxic coplanar PCBs: Occurrence, source, persistency and toxic implications to wildlife and humans.* Environmental Pollution **42**, pp. 147 -160.

[31] *op. cit* 5, p. 28.

[32] Konemann, W. H. (1984) Ecotoxicology and Environmental Quality. In: Environmental Protection: Standards, Compliance and Cost. (ed. T. J. Lack). Ellis Horwood, Chichester, UK.

[33] Wheeler, A (1978) *Key to the Fishes of Northern Europe,* p.67. Frederick Warne, London.

[34] *ibid,* p. 326.

[35] *op. cit.* 9, Table 5, pp. 9–12.

[36] Johnston, P. A. , Booth, A. M. and Thorpe, B.G. (1987). *Monitoring programmes, consented discharges and the detection of environmental effect in estuaries and coastal waters.* pp. 19-21. Submission to the House of Commons Environmental Committee 1987 by Greenpeace UK. Greenpeace UK, 31 Islington Green, London.

[37] Arlt, G. (1975) *Remarks on indicator organisms (meiofauna) in the coastal waters of the GDR.* Merent. Julk. / Havsforskninginst. Skr., **239**, pp. 272-279.

[38] McIntyre, A. D. (1977) *Effects of pollution on inshore benthos.* pp. 301-18 in: Ecology of Marine Benthos, ed. B. C. Coull. University of South Carolina Press, Columbia.

[39] Newton, A. J., Henderson, A. R., and Holmes, P. J. (1979) Monitoring the effects of domestic and industrial wastes. pp 171-179 in: Monitoring the Marine Environment (ed. D. Nichols). Institute of Biological Symposium

[40] *op. cit* 4, Annex 18, paras 7–8, p. 128.

[41] Southwood, T. R. E. (1978) Ecological Methods; with particular reference to the study of Insect Populations. Chapman and Hall, London.

[42] *op cit* 15, pp. 193-99.

[43] *op cit* 9, p. 5.