**division of technology for society**

netherlands organization for
applied scientific research



Rapport nr. : R85/217
Opdracht nr. : 10556
Datum : 02-10-1985

# MODELLING BIOACCUMULATION AND ELIMINATION DYNAMICS OF SOME XENOBIOTIC POLLUTANTS (Cd, Hg, PCB, HCB) BASED ON "IN SITU" OBSERVATIONS WITH MYTILUS EDULIS.

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ABSTRACT

Concentrations and body burdens of bio-available Hg, Cd, HCB and PCB isomers were measured by analysing samples of mussels, Mytilus edulis, L in the Eastern Scheldt (location: Kats) and the more heavily polluted Western Scheldt Estuary (location Perkpolder).
Despite practical difficulties data could be gathered on the rates of bio-accumulation and elimination of Cd and PCB-101, -138 and -153 under field circumstances by simultaneous transplantations of mussel sample series between these two areas. Mathematical model exercises showed Cd-accumulation and elimination of exchangeable Cd to be slow processes (equilibrium reached in 150 days). In this case Mytilus edulis presumably functioned as a two-compartment system firmly retaining a less readily exchangeable part of the accumulated cadmium in internal structures. PCB-isomer accumulation and elimination processes showed a somewhat more dynamic character (equilibrium reached in 45 days) with similar rate constants and complete elimination to base-line levels, suggesting the existence of reversible uptake and loss processes in a simple one-compartment system.

# 1. INTRODUCTION

## 1.1 MONITORING BY TRANSPLANTATION OF MUSSELS

Mussels are extensively applied as quantitative bioindicators of marine pollution. The filter feeding genus Mytilus appears to fulfil the basic prerequisites of a monitoring organism, as listed by Phillips (1977, 1980). Practical reasons prevail among these, e.g. wide distribution, abundance, size, ease of collecting, long life span, euryhalinity, general stress tolerance, accumulation ability and high concentration factors for several xenobiotics. Monitoring schemes using Mytilus edulis are known in, e.g., the U.S.A ("mussel watch" Goldberg et al; 1978) and on the international scene (Joint monitoring Group, ICES).
To avoid natural variability related to factors such as age, size or vertical position on the shoreline, various attempts have been described in wich bio-available pollutants were measured by transplanting M. edulis to pollution gradients. Succesful efforts have been reported for, e.g., Hg, Cu and Zn in the Netherlands (Hueck, 1976), Hg in Scotland (Davies and Pirie, 1978), Zn and Pb in the U.K. (Simpson, 1979) and various metals and hydrocarbons in Narragansett Bay, R.I., U.S.A. (Widdows et al; 1981). De Kock and Kuiper (1981) reported how temporal variation of total Hg levels in M. edulis could be reduced by changing from a "passive" monitoring scheme with mussels sampled from the Dutch intertidal zone to an "active" biomonitoring approach, in wich large samples of continuously submerged animals of a selected size class were transplanted from a relatively unpolluted site to the target area and suspended from buoys in cages. Such a transplantation technique may provide a useful approach because (1) it facilitates comparison between geographical locations by employing statistically similar groups of animals derived from a common stock, (2) the (chosen) period of exposure to the polluted environment is known, and (3) the investigator can select his monitoring locations regardless of whether or not the monitoring species occur there naturally.

To resolve differences in mean pollutant levels between series of samples by monitoring, every effort must be made to minimize population variance. For the sake of the underlying report this has been done as before (De Kock and

Marquenie, 1981) by using animals of a single length class from the same non spawning stock, and by apportioning them randomly to experimental samples of 75-100 mussels each. This random set-up with large samples should eliminate most of the variability between samples at the start of the transplantation experiments. Gordon et al. (1980) showed with Mytilus californianus, for a number of trace metals, in what way the required number of analyses of individual animals changes with the percentage difference between population means that can be detected. Resolution is much improved when the number of individual analyses used for one sample increases up to a sample size of about 30 individuals; but clearly, the analytical workload restricts the usefulness of this approach (certainly so for gas-chromatographic analysis of organic pollutants).
For Cd in M. californianus Gordon et al. (1980) report that 60-80 individual analyses are required to detect a 20% difference between means by the t-test.

The advantage of pooling many individual organisms into a single sample is that it affords a good estimate of the mean concentration of a pollutant in a population without the need of too much analytical work. De Wolf (1975), for example, observed that pooled samples of at least 60 individuals of M. edulis in each 0.5-cm length class were needed to obtain a measured Hg concentration falling within ± 10% of the population mean with a probability of 95%. Martin and Phelps (1979) plotted the relation between number of pooled M. edulis samples and number of individuals per pool giving concentrations with P = 0.05 for various degrees of resolution (5, 10, 20, 50 or 100%) using a t-test. Extrapolation of these plots indicates that when a pool contains 100 individuals, only very few (possibly 1) samples are required even for detecting a 5% difference between means. Unfortunately, such plots are not available for HCB, PCB, Hg and Cd in the present study. It is assumed, however, that 75-100 pooled and randomly selected individuals per sample should constitute a fairly reliable sample size. In this case, resolution power is likely to be limited in the end by analytical reliability.

In the present study variation coefficients were determined for the contaminant values in a standard homogenate of mussel tissue, kept deep frozen in the laboratory and routinely analysed simultaneously with the experimental field samples (table 5). At P = 0.05 and assuming normality, real contami-

nant values will deviate no more than 2 standard deviations from the measured concentrations (Cd: 29.0%, Hg: 12.2%, HCB: 12.2%, PCB isomers: 7.0 - 22.8%).

## 1.2 ACCUMULATION AND ELIMINATION OF POLLUTANTS; DEFINING THE PROBLEM

### 1.2.1 Inadequacy of earlier field data

In 1979-1980 a study was undertaken to investigate the spatial and temporal distribution of various pollutants in Dutch coastal waters. By application of the transplantation concept measurements were made of the actual bio-accumulation process along pollution gradients caused by fluvial input from the Scheldt, Rhine and Meuse. MT-TNO report MD-N&E 81/2 (De Kock and Marquenie, 1981) gives the levels of heavy metals (Cd, Zn, Cu, Cr, Pb, Hg, Ag) and chlorinated hydrocarbons [Aldrin, Endrin, Dieldrin, op-DDT, pp-DDT, op-DDD, pp-DDD, op-DDE, pp-DDE, HCB and PCB (perchlorinated to DCB)] 10, 25 and 60 days after transplantation of M.edulis samples from the western Atlantic coast of Ireland to their destination in Dutch coastal waters. The data for Cd, Hg, DCB, HCB in the Western Scheldt are given in Table 1. Concentrations - especially those for the period June-August 1980, when the whole length of the estuary was covered, demonstrate east-west gradients for Cd, HCB and DCB with the highest levels occurring in the eastern part after 60 days exposure. The pattern for Hg was less clearly related to river run-off; in contrast relatively high Hg levels were found even outside the estuary in the period November 1979 - January 1980. (See Figure 1).

Whereas the applied transplantation technique might have provided a good resolution power with regard to intercomparison of locations, it did afford inadequate information on the precise dynamics of the observed accumulation process.
The reason for this is twofold:

- the number and frequency of observations was low.
- the ambient bio-available pollutant concentration could have changed over the experimental period, leading to deviations in the shape of the accumulation curve, which should theoretically reach an equilibrium value at constant environmental pollutant concentrations.

### 1.2.2 Need for a description of accumulation - elimination dynamics

There is, therefore, a need for a reliable accumulation - elimination model, with a predictive value that satisfactorily estimates equilibrium levels of environmental toxicants from relatively few measurements within a relatively short period of exposure.
The construction of such a model for Mytilus edulis should at least be based on a single accurate field description of the accumulation and elimination pattern of different pollutants. Accumulation is defined as the net positive result of uptake and loss in time; elimination is the net negative result of uptake and loss in time. Accumulation and elimination are the usual result of increased, respectively decreased bio-available pollutant concentrations in the animal's environment. Knowledge of the accumulation pattern implies that equilibrium levels of pollutants in living mussel tissue can be estimated from the shape of the curve. It is such equilibrium levels that characterize the average environmental supply of a bio-available pollutant fraction in a certain location after a certain period has elapsed. The location may be one situated in a pollution gradient, the period is pollutant-specific and will depend on the combined rates of uptake and loss by the organism.

These considerations are important for the correct application of mussels in bio-monitoring schemes. For bio-monitoring purposes, one should try to establish pollution trends routinely by the repeated measurement of equilibrium levels in space and/or time. From the viewpoint of water quality management this is important for estimating the effectiveness of clean-up schemes, the self-recovery potential of polluted systems, for assessing the consequences of disasters (more specifically the distribution of chemicals, and toxic levels for organisms), and for the control of legal dumping practices, or detection of suspected illegal sources.

### 1.2.3 Choice of experimental locations

Duursma et al. (1984) showed that mussels taken from the Eastern Scheldt differed in HCB and PCB content from mussels taken from the Western Scheldt. Mean concentrations (expressed on basis of total lipids), together with their standard deviations, are summarized in Table 2.

They have been calculated from a time series with samples taken at regular intervals between Nov. 1979 and Nov. 1981. Samples normally consisted of 50 individuals of 4.0-6.0 cm length, taken from the intertidal zone at three locations in the Eastern Scheldt (Colijnsplaat, Wemeldinge and Yerseke) and one site in the Western Scheldt (Hoedekenskerke). The standard deviation is a measure of temporal variation and analytical variation combined. For purposes of comparison, Table 2 also lists data for the Western Scheldt gathered from the transplantation experiment mentioned above (Table 1), after 60 days exposure at a location near Hoedekenskerke and covering a single winter and summer observation.

Bio-available HCB concentrations do not seem to differ substantially between the two water bodies. In the Western Scheldt, however, PCB concentrations are clearly about 2 - 6 times higher than those in the Eastern Scheldt.
De Kock (1983) summarized TNO-data on metal levels in some bivalve molluscs (Mytilus edulis, Macoma balthica, Scrobicularia plana) from surveys in the tidal zone of Dutch coastal waters. Table 3 lists data for Cd and Hg. Whereas differences in bio-available Hg are not clearly discernible, Cd-data show the range of levels in the Western Scheldt to be higher than those in the Eastern Scheldt. As regards the chosen pollutants (Cd, Hg, PCB, HCB), the available information thus shows at least that the concentration of bio-available Cd and PCB is higher in the Western Scheldt Estuary (especially the eastern part of it) than in the Eastern Scheldt basin.
Because of the coexistence of different pollution regimes in the same part of the Netherlands, the opportunity was taken to conduct a more detailed accumulation - elimination experiment in which mussel samples could be transplanted from a more polluted environment and vice versa without unmanageable logistics. The goal was to collect sufficient data to describe the dynamics of the accumulation and elimination process of total Cd and PCB isomers under field conditions and - if possible - to obtain data on total Hg and HCB simultaneously for the same purpose.

## 2. METHODS AND MATERIALS

### 2.1 FIELD WORK

On 22 March 1983, mussels (Mytilus edulis) of 3.0-4.5 cm length were collected from buoy 22 in the Western Scheldt Estuary, divided into 25 random samples of 75 individuals each and suspended in polyethylene baskets in the nearby Perkpolder Ferry Harbour before use in the experiment. Likewise, mussels of 3.0-4.5 cm were collected on 5 April 1983 from a location in the low littoral zone near Kats in the Eastern Scheldt, and divided into 25 random samples of 90 individuals each.

At the start of the experiment on 5 April 1983, a batch of 8 samples (series 1) was taken from the Eastern to the Western Scheldt (location: Perkpolder Harbour), and vice versa from the Western to the Eastern Scheldt (location: Kats Harbour). Additionally a blank sample was retained. The remaining samples were kept in their areas of origin.
Subsequently and in the same manner 7 samples were transplanted from the Eastern Scheldt and vice versa on 11 May 1983 (series 2), again with additional retention of one sample. Finally, on 6 June 1983 a third batch of 7 samples (series 3) underwent the same procedure and another additional blank sample was retained. From 6 June 1983 onwards, samples were retrieved from the three series, as shown in the scheme of Table 4.
A control sample from the Eastern Scheldt was kept on location Kats in the area of origin during the whole 122-day period of exposure. Such a sample from the Western Scheldt was not available; it was lost together with 2 samples from accumulation series 1 due to disturbance by shipping operations in Perkpolder Harbour in the period 16 May 1983 - 20 June 1983. A low littoral sample was, however, collected on 27 October 1983 near Perkpolder. Photographs of the detail locations in Perkpolder and Kats Harbour are presented in figures 2a and 2b, respectively. The polyethylene baskets (average mesh size about 1.5 $cm^2$) containing the samples were packed in epoxy-coated iron cages (20 kg; 60 x 55 x 30 cm) and suspended from floating pontoons at about 2 m depth. There they were directly exposed to the tidal water regime entering the harbour basins.

## 2.2 SAMPLE TREATMENT AND ANALYSIS

After being recovered, live samples were thoroughly rinsed with sea water at the exposure location to remove associated silt (pseudofaeces, faeces) and/or small fouling organisms (barnacles, hydroids). A purification period was considered to be of no special advantage, in agreement with Boalch et al. (1981), and samples were at once deepfrozen in polyethylene bags at -20°C in the laboratory. Subsequent treatment involved thawing at room temperature, severing the posterior adductor muscle, carefully draining interior water (20 min.), removing all soft tissues with a titanium scalpel, and mixing with a homogenizer (Ultra-Turrax, modified with a titanium rotor shaft and cutting blades). Homogenates thus consisted of the pooled tissues of all the individuals in a sample. Subsamples of homogenates were stored either in acid-cleaned beakers for metal analysis or acetone-cleaned beakers dried at 260°C and closed with aluminium foil for organic pollutant analysis. Subsamples of a standard homogenate kept at the laboratory were treated and analysed in the same way. Cadmium and total mercury were determined by neutron activation analysis.

The determination of PCB isomers, HCB and pp-DDE involved several steps:

(a) enzymatic destruction of the subsamples,

(b) isolation of the components using extractive steam distillation with n-hexane, followed by column chromatographic elution over alumina,

(c) gas-chromatographic analysis with electron capture detection on a 50 m fused silica CP SIL 19 CB column.

The statistics of the analysis of the standard homogenates are given in Table 5.

Separate subsamples were used to determine dry weight (after 16 h at 105°C) and ash content (after 4 h at 600°C). This was done to express analytical results on an ash-free dry weight basis. Using merely a dry weight basis may introduce bias due to salinity variations in the tissue fluids of Mytilus edulis, especially in estuarine areas. Mytulis edulis is highly isotonic with its external environment (Potts 1954), and its ash is composed largely (± 75%) of inorganic sea salt components, as has been found by analysis of major cations and anions ($Na^+$, $K^+$, $Mg^{++}$, $Ca^{++}$, $Cl^-$, $SO_4^{--}$). Furthermore, we have found exp. that significant linear correlations between ash content and water content are shifted upon transfer of test animal samples to environments of different salinities.

## 3. OBSERVATIONS

Results of Cd, Hg, PCB and HCB measurements of the three accumulation and elimination series are presented in Table 6a and 6b. The PCB results are given for various more or less highly chlorinated components, viz. PCB 28, 49, 52, 70, 87, 101, 138, 153 and 180.
Moreover, the tables present data for pp-DDE that could easily be produced from the gas chromatographic procedure applied. The data at zero exposure time representing "naturally" occurring contaminant concentrations from both the Eastern and Western Scheldt at the start of the three accumulation and elimination exposure series (at t=0, t=36 and t=62 days) are presented in Table 7 and Figure 3, together with one Eastern Scheldt sample kept until t=122 days, and some observations on unexposed samples. Obviously, bio-available concentrations of Hg and HCB do not differ greatly between the two areas, in accordance with information gathered earlier (cf. chapter 1). Levels of Cd and the more highly chlorinated PCB comp. (P-101, P-138, P-153) are, however, clearly higher in the Western Scheldt estuary. Levels of the less chlorinated isomers (P28, 49, 52, 70, 87) and also P180 show systematic differences. These are, however, less easy to quantify, because a great many data for the Eastern Scheldt fall below the analytical detection limit.

Table 7 and Figure 4 show the ash-free dry weight per mussel of the non-transplanted samples. It should be borne in mind that the samples were not treated in the same way, the difference being that the samples for t=36, t=62 and t=122 days were experimental samples kept in baskets since t=0, and those for t=-14, t=0 and t=205 were "passively" sampled directly from the environment. It should be remarked, first, that mussels from the Eastern Scheldt of 3.0-4.5 cm had consistently higher ash-free dry weights than those from the Western Scheldt, and, secondly, that the random experimental samples for t=0 to t=122 days show erratic weights, perhaps together with a slight tendency for tissue growth towards the autumn. The available data do not permit of a ready explanation for the weight differences. Several factors may influence weight, growth or condition. Such factors include salinity, temperature, oxygen concentration, availability of food, amount of suspended material (silt), presence of pollutants, etc., all of which operate simultaneously in the ecosystem. The data at least suggest that conditions for growth in the Eastern Scheldt are better. Mean ash-free

weights are 239.45 mg (n=4, s=31.32) and 159.46 mg (n=5, s=57.89) for the Kats (Eastern Scheldt) and Perkpolder (Western Scheldt) locations, respectively.

Data on ash-free dry weight trends in the transplantation experiments are listed in Table 6a and Figure 5. Clearly, there are rather serious irregularities (up to a 50% difference between two consecutive sampling dates), suggesting that the samples were not taken randomly enough from the original stock. It should be remarked that a length class of 3.0-4.5 cm. was used.

A length difference of 1.5 cm means that relatively large individual weight differences presumably occurred in the original stock.
Individual weights have not, however, been determined. Moreover, the possibility of short-term weight loss of some samples as a result of spawning cannot be excluded, but this does not explain short-term weight gains between successive samples. Spawning was not observed, nor was it investigated in detail.
Despite the weight irregularities, there is a tendency for better growth in the elimination series in the Eastern Scheldt during the experimental period. When we express growth as a percentage in comparison with the sample t=0 from each series (growth having either positive or negative values) then most of these relative values are located Eastern Scheldt basin ("elimination series"). This is presented in Figure 6. The weight irregularities might have introduced irregularities in contaminant concentrations, which in turn could hamper the intended construction of an accumulation-elimination model (Chapter IV). A way to treat this problem is to carry out calculations with a data set of contaminant concentrations (contaminant weight per unit weight of animal tissue) converted into contaminant contents (contaminant weight per animal). This could diminish the disturbing factor of "tissue dilution" coinciding with growth. Such data have also been used in the modelling attempt in Chapter IV.

# 4. MODELLING ATTEMPT

## 4.1 TREATMENT OF DATA

We have at our disposal the data of Table 6. Table 6a contains the observations on Cd, Hg, HCB and PCB isomer concentrations (contaminant weight per unit animal weight) in mussel tissue homogenates from series of samples retrieved in three accumulation experiments with Eastern Scheldt mussels exposed in the Western Scheldt and three elimination experiments simultaneously conducted with Western Scheldt mussels exposed in the Eastern Scheldt. Table 6b similarly contains the calculated data representing the amount (content) of contaminant per animal for each sample. For the modelling exercise presented below, we limit ourselves to Cd and the PCB components 101, 138 and 153, because:

- differences in total Hg and HCB concentrations between the Eastern Scheldt sample series are insufficient (see Figure 3);
- many of the values for other PCB components (PCB 28, 49, 52, 70, 87, 180) fall below the analytical detection limit.

For the purpose of estimating rates of accumulation and elimination, the data on Cd and PCB 101, 138 and 153 were treated as indicated below (a and b).

Primary assumptions are:

- Mytilus edulis is a one-compartment unit;
- contaminant uptake and loss are only dependent on the ambient bioavailable contaminant concentration and not on other environmental variables or physiological factors;
- equilibrium is reached as a consequence of simultaneous uptake and loss processes.

a. accumulation and elimination considered as fully reversible processes, in which the time constant ($\tau$) for the rate at which contaminant concentrations (or contents) change with the time is identical:

$$\tau \text{ accumulation} = \tau \text{ elimination}$$

Then:

(accumulation) $Q_t = Q_E \cdot e^{-t/\tau} + Q_W (1 - e^{-t/\tau})$

(elimination) $Q_t = Q_W \cdot e^{-t/\tau} + Q_E (1 - e^{-t/\tau})$

where: $Q_t$ = contaminant concentration (or content) at time t

$Q_E$ = equilibrium contaminant concentration (or content) in the Eastern Scheldt

$Q_W$ = equilibrium contaminant concentration (or content) in the Western Scheldt

$\tau$ = time constant for the accumulation or elimination process, a parameter for the rate at which concentrations (or contents) change. $\tau$ represents the time in which a concentration - (or content) increase or - decrease of 63% occurs.

The model estimates $Q_E$, $Q_W$ and $\tau$ from the exposure data, using the combined data of all three accumulation series in the Western Scheldt. The available data sets used are those for concentrations on an ash-free dry weight basis (Table 6a) as well as for contents per animal (Table 6b).

b. accumulation and elimination considered as separate processes with different rate constants.

Here also, we assume that accumulation and elimination patterns obey a first-order kinetics, the contaminant concentration at time = t being:

(accumulation) $Q_t = Q_o + A(1 - e^{-t/\tau a})$ or: $Q_t = (Q_o + A) - A \cdot e^{-t/\tau a}$

(elimination) $Q_t = (Q_o + A) - A (1 - e^{-t/\tau e})$ or: $Q_t = Q_o + A \cdot e^{-t/\tau e}$

where: $Q_t$ = contaminant concentration (or content) in the tissues at time t

$Q_o$ = equilibrium contaminant concentration (or content) in the tissues under the least contaminated conditions (Eastern Scheldt)

A = difference between contaminant concentrations (or contents) at t=0 and t=∞

$\tau_a$ = time constant for the accumulation process, a parameter for the rate at which contaminant concentrations (or contents) change. $\tau_a$ represents the time in which a concentration (or content) increase of 0.63 A occurs.

$\tau_e$ = time constant for the elimination process. $\tau_e$ represents the time in which a concentration - (or content) decrease of 0.63 A occurs.

Figure 7 presents these parameters schematically. The model estimates the value of $Q_o$ (in $\mu g.g.^{-1}$). $\tau$ (in days) and $(Q_o + A)$ (in $\mu g.g^{-1}$) with their 95% confidence intervals.

This is carried out for the following data sets:

b.1. - (accumulation process:) The difference of contaminant content (contaminant weight per animal) between series 1 and 3 and series 2 and 3 at the same date of collection versus time of exposure, starting with t = 0 for series 3 (t = 62 for series 1, t = 26 for series 2) up to t = 60 for series 3 (t = 122 for series 1, t = 86 for series 2). In Figure 8 the difference between series 2 and 3 is plotted with a time shift of 26 days in the relationship for the difference between series 3 and 1 with time.

- (elimination process:) same procedure

b.2. - accumulation: The concentrations for the three accumulation series 1, 2 and 3 combined in one set. The data are somewhat clustered: series 1 lasted 122 days with a cluster of frequent observations starting at t = 62. Series 2 lasted 86 days with a cluster of frequent observations starting at t = 26. Series 3 lasted 60 days with a cluster of frequent observations starting at t = 0.

- elimination: same procedure

b.3. - accumulation: the contents per animal for the three series 1, 2 and 3 combined. Compare b.3.

- elimination: same procedure.

b.4. - accumulation: The concentrations of series 3 only.
- elimination: same procedure.

b.5. - accumulation: The contents of series 3 only.
- elimination: same procedure.

4.2 RESULTS

The data needed for the model calculations b.2.-b.5 are listed in Tables 6.a.b. and Figure 9.

The outcome of the modelling exercise is presented in Table 8 ($a_1$, $a_2$) and 8 ($b_1$ - $b_5$) below.
Tables 8 ($a_1$, $a_2$) concern the situation where $\tau_a = \tau_e$; in tables 8 ($b_1$ - $b_5$), parameter values are separated for the accumulation and elimination process.

## 5. DISCUSSION

This report presents the results of a field experiment carried out in an area where the exchange of mussels between water bodies exposed to different degrees of pollution could easily be arranged. The use of the field situation is justified by two arguments:

(1) The physico-chemical form in which pollutants occur depends on many abiotic factors, such as salinity, pH, oxygen concentration, dissolved and particulate organic matter, amount and composition of silt in suspension, etc. As yet it is hardly possible to predict with accuracy the details of metal speciation or the partition of organic micro-pollutants for areas like the Western and Eastern Scheldt. It is at present even less possible to predict the bio-availability of pollutants from abiotic data on total dissolved or particulate pollutant concentrations, as are routinely measured by water management authorities. "Active biomonitoring" should therefore be seen as a bio-assay procedure affording information not otherwise obtainable on bio-availability and specific accumulation-elimination dynamics.

(2) The field situation offers the necessary food supply for a large scale experiment such as the one described. It should, however, be remarked that the processes of accumulation and elimination should also be studied on a smaller scale in the laboratory with differently partitioned metals and organic pollutants under strictly controlled conditions. Such experiments would improve our insight into the relative importance of various chemical forms as causal factors of possible toxic effects in biological systems. The selection of the controlled experimental conditions should in that case depend on prior practical information derived from the field, regarding critical pollutants to be chosen etc.

Field experimentation is, however, complicated. Presumably, the main drawback of the experiment has been at the onset the difficulty of selecting animals with corresponding weights between Western and Eastern Scheldt within the same length class. Moreover, the length class used (3.0-4.5 cm) was rather wide, probably introducing undesirable variability. It has been especially difficult to find contaminated mussels in the Western Scheldt estuary for use in the elimination phase of the experiment. The buoy near

Perkpolder Harbour (buoy 22) from which they were collected housed only a small population of low-weight mussels, from which a narrower length class could not be selected. In future work it might be wise to prepare stocks of animals beforehand from a suitable mother population by exposing them in the contaminated and uncontaminated area for a few months before the actual experiment.

Another serious problem might have been caused by unexpected dredging operations in Perkpolder Harbour during part of the experimental period. These dredging activities lasted from May 16th to June 20th, 1983. As a result increased amounts of contaminated suspended sediment as well as contaminated interstitial water could easily have been carried to the cages with mussels by tidal turbulence in the harbour basin. It should be remarked that contaminant concentrations in mussels exposed in Perkpolder Harbour showed more temporal irregularities than those observed in the Eastern Scheldt exponates.

The large variation in PCB isomer concentrations will - apart from biological sample variability - also be determined by analytical variations. Figure 3 demonstrates that different components show corresponding patterns in time, not easily explained by accumulation - and elimination dynamics, but possibly attributable to differences between samples in the recovery rate of the extraction procedure. The recovery of the extraction is normally some 80-90%. The data in this report have not been corrected for recovery differences.

Notwithstanding the difficulties encountered, it has been possible to derive an estimate of the time dimensions involved for the accumulation and elimination of cadmium and the three more highly chlorinated PCB components 101, 138 and 153. The ranges for $\tau$ found with different treatments of the data are compiled in Table 9. Only $\tau$-values calculated for accumulation and elimination as separate processes with separate rate constants ($\tau_a \neq \tau_e$) are considered.

$\tau$ is defined as the time needed for attainment of a 63% concentration (or content) difference from the initial concentration or content. This is illustrated in Figure 10. The relation between $\tau$ and the biological "half-life" of the pollutant (a 50% difference) is derived from
$e^{-t/\tau} = 0.5$ or $t(0.5) = 0.693\ \tau$.

It is also seen that the time needed for equilibrium being approached to within 5% of the actual equilibrium value is $\sim 3\tau$. This is already within the usual analytical variation range of various pollutants, and greater accuracy in estimating accumulation or elimination times is not considered necessary.

Table 9 shows that accumulation and elimination of cadmium are both slow processes with $\tau \sim 50$ days, implying that equilibrium is reached in $\sim 150$ days. The dynamics of PCBs are, in comparison, more rapid, with $\tau \sim 15$ days for the accumulation and for the elimination process, leading to equilibrium in $\sim 45$ days. Tables 10 show that in contrast with cadmium, elimination of the PCB seems to be complete, down to initial equilibrium levels, once the animals have been taken to a less contaminated environment. Some cadmium is always retained, as was also observed in earlier work with the Zebra mussel Dreisena polymorpha in fresh water systems (Marquenie 1981; 1984). The cadmium probably forms a firm bond with proteins in the animal cell.

Whereas for PCB estimates, if the appropriate model (accumulation or elimination) is used, exposure periods of about two weeks seem to be sufficient, we suggest that, for general monitoring purposes, exposure periods of about 50 days should be taken so as to provide for the need of registering the slow accumulation of bio-available metals as well as the accumulation of bio-available organic pollutants like PCBs, however, precise determination of $\tau$ for many specific pollutants awaits further experimentation. In the work reported here this has not been possible for Hg and HCB, owing to the similarity in contaminant levels for these substances. Although our experiments may suggest that Hg and HCB are a less serious immediate threat to life in the Western Scheldt than are Cd and PCBs, they also show that bio-available mercury has entered the Eastern Scheldt (possibly from external sources), causing mussels to accumulate more mercury than their Atlantic congeners (Table 1.). HCB levels may also be slightly higher in the Eastern Scheldt.

## 6. CONCLUSIONS

1. Analysis of mussel tissue (Mytilus edulis) showed Perkpolder Harbour (Western Scheldt Estuary) to be more contaminated with bio-available cadmium and PCB components than Kats Harbour (Eastern Scheldt Basin); differences in bio-available levels of mercury and HCB could not, however, be demonstrated. These findings relate to the situation in 1983.

2. It has been possible to measure accumulation and elimination dynamics of Cd and the PCB comp. 101, 138 and 153 in the field by experiments with Mytilus edulis samples simultaneously transplanted from the Eastern to the Western Scheldt and vice versa. Cd accumulation is a slow process, equilibrium values being reached after about 150 days. By comparison, PCB isomer accumulation is faster, equilibrium values being reached after about 45 days.
   Similar rate constants were found for the three isomers. Less highly chlorinated isomers could not be studied, because many of the data fell below the gas-chromatographic detection limit. The way in which Cd is eliminated suggests the existence of a two-compartment process. A proportion of the Cd is eliminated with a rate constant similar to that of accumulation, most of the remainder being retained. The rate of PCB isomer elimination is comparable to that of accumulation, leading to original background values when test animal samples are returned to the Eastern Scheldt.

3. It is probable that lack of statistically sound samples, dredging operations in Perkpolder Harbour and, perhaps, loss of spawning products, caused undesirable variation and impaired the modelling. Nevertheless, the modelling exercise described here has been useful in establishing what exposure periods are necessary for important pollutants when the method of transplanting mussel samples is used as a bio-monitoring tool.

## 7. REFERENCES

Boalch. R., S. Chan, and D. Taylor. 1981. Seasonal variation in the trace metal content of Mytilus edulis. Mar. Pollut. Bull. 12: 276-280.

Davies, I.M., and J.M. Pirie. 1978. The mussel Mytilus edulis as a bio-assay organism for mercury in sea water. Mar. Pollut. Bull. 9: 128-132.

De Kock, W.C., and J. Kuiper. 1981. Possibilities for marine pollution research at the ecosystem level. Chemosphere 10: 575-603.

De Wolf, P. 1975. Mercury content of mussels from West European coasts. Mar. Pollut. Bull. 6: 61-63.

Goldberg, E.D., V.T. Bowen, J.W. Farrington, G. Harvey, J.H. Martin, P.L. Parker, R.W. Risebrough, W. Robertson, E. Schneider, and E. Gamble. 1978. The mussel watch. Environ. Conserv. 5: 101-125.

Gordon, M., G. Knauer, and J.H. Martin. 1980. Mytilus californianus as a bio-indicator of trace metal pollution: variability and statistical considerations. Mar. Pollut. Bull. 11: 195-198.

Hueck, H.J. 1976. Active surveillance and use of bio-indicators. p. 275-286. In R. Amavis and J. Smeets (ed.) Principles and methods for determining ecological criteria on hydrobiocenoses (Commission of the European Communities). Pergamon Press. Oxford, New York, Toronto.

Marquenie, J.M. 1981. The freshwater mollusc, Dreissema polymorpha as a potential tool for assessing bio-availability of heavy metals in aquatic systems. Proc. Int. Conf. Heavy metals in the environment, Amsterdam. CEP Consultants, Edinburgh: 409-412.

Marquenie, J.M. 1984. Opname en afgifte door organismen. In: Zware metalen in aquatische systemen. Deel 4. Rijkswaterstaat, RIZA, Lelystad, 56 pp.

Martin, J.H., and D. Phelps. 1979. Bio-accumulation of heavy metals by littoral and pelagic marine organisms. EPA Final Rep. No. 600/3-79/038. U.S. Environmental Protection Agency, Washington, DC.

Phillips, D.H. 1977. The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments - a review. Environ. Pollut. 13: 281-317.

1980. Quantitative aquatic biological indicators (Pollution Monitoring Series), 488 p. Applied Science Publishers Ltd., London.

Potts, W.T.W. 1954. The inorganic composition of the blood of Mytilus edulis and Anodonta cygnea. J. Exp. Biol. 31: 376-386.

Simpson, R.D. 1979. Uptake and loss of zinc and lead by mussels (Mytilus edulis) and relationships with body weight and reproductive cycle. Mar. Pollut. Bull. 10: 74-78.

Widdows, J., D.K. Phelps, and W. Galloway. 1981. Measurement of physiological condition of mussels transplanted along a pollution gradient in Narragansett Bay. Mar. Environ. Res. 4: 181-194.

Kock, W.Chr. de en J.M. Marquenie. 1981. De experimentele toepassing van de mossel, Mytilus edulis, L., bij het meten van zware metalen en organische microverontreinigingen in Nederlandse kustwateren. Rapport MT-TNO MD-N&E 81/2, Delft, The Netherlands.

Kock, W.Chr. de. 1983. Referentiewaarden zoute wateren; zware metalen in mariene organismen. Discussiestuk TNO D 83/133, Delft, The Netherlands.

Rijkswaterstaat. 1984. Zware metalen in aquatische systemen (ZMAS). RIZA, Lelystad, 7 delen.

Rijkswaterstaat. 1983. De waterkwaliteit van de Noordzee, 1975-1982. Nota 83.084, Lelystad, October 1983.

Duursma, E.K., J. Nieuwenhuis and J.M. van Liere. 1984. Organochlorine contamination of the Dutch Delta region as "watched" by mussels. Delta Institute for Hydrobiological Research, Yerseke, The Netherlands, comm. no. Δ-244. P. 1-29.

Roesijadi, G., J.S. Young, A.S. Drum and J.M. Gurtisen. 1984. Behavior of trace metals in Mytilus edulis during a reciprocal transplant field experiment. Marine Ecology - Progress series 18: 155-170.

TABLES 1 - 10

Table 1 Active Bio-monitoring experiments in the Western Scheldt Estuary. Contaminant concentrations in soft tissue homogenates on basis of ash-free dry weight Mytilus edulis, 4-5 cm length class; sample size 100 individuals

| | | Cd ($\mu g.kg^{-1}$) exposure (days) | | | Hg ($\mu g.kg^{-1}$) exposure (days) | | |
|---|---|---|---|---|---|---|---|
| location | period | 10 | 25 | 60 | 10 | 25 | 60 |
| series 1: | | | | | | | |
| Atl. coast Ireland | Nov.'79 | 0 days: 650 (SD=130, n=4) | | | 0 days: 56 (SD=18, n=3) | | |
| Deurloo | Nov.'79-Jan.'80 | 562 | 528 | 690 | 306 | 440 | 367 |
| Nieuwesluis | Nov.'79-Jan.'80 | -- | -- | 891 | -- | -- | 376 |
| Hoek van Baarland | Nov.'79-Jan.'80 | 1017 | 1675 | 3066 | 92 | 153 | 125 |
| series 2: | | | | | | | |
| Atl. coast Ireland | June'80 | 0 days: 930 (SD=40, n=5) | | | 0 days: 69 (SD=9, n=5) | | |
| Westpit | June-Aug.'80 | 638 | 455 | 665 | 88 | 94 | 92 |
| PvN/E | June-Aug.'80 | 1252 | 1044 | 3590 | 94 | 104 | 180 |
| MG/E | June-Aug.'80 | 2098 | 1900 | 6527 | 92 | 130 | 187 |
| NvB/SvN | June-Aug.'80 | 1906 | 3243 | 5798 | 88 | 130 | 145 |

| | | |
|---|---|---|
| Standard, series 1 | Cd: var. coeff. 9.0%, n=9 | Hg: var. coeff. 9.2%, n=6 |
| Standard, series 2 | Cd: var. coeff. 7.3%, n=8 | Hg: var. coeff. 11.2%, n=7 |

Table 1 (cont.)

| location | period | HCB ($\mu g.kg^{-1}$) exposure (days) 10 | 25 | 60 | PCB ($\mu g.kg^{-1}$) exposure (days) 10 | 25 | 60 |
|---|---|---|---|---|---|---|---|
| series 1: | | | | | | | |
| Atl. coast Ireland | Nov.'79 | 0 days: 2 (SD=5, n=5) | | | 0 days: 858 (SD=809, n=5) | | |
| Deurloo | Nov.'79-Jan.'80 | 15 | 38 | 3 | 572 | 7477 | 4981 |
| Nieuwesluis | Nov.'79-Jan.'80 | -- | -- | 13 | -- | -- | 4463 |
| Hoek van Baarland | Nov.'79-Jan.'80 | 6 | 92 | 14 | 1637 | 1526 | 12822 |
| series 2: | | | | | | | |
| Atl. coast Ireland | June'80 | 0 days: 2 (SD=2, n=5) | | | 0 days: 89 (SD=127, n=5) | | |
| Westpit | June-Aug.'80 | 4 | -- | 6 | 669 | -- | 2248 |
| PvN/E | June-Aug.'80 | -- | 5 | 6 | 1186 | 896 | 3571 |
| MG/E | June-Aug.'80 | 5 | 5 | 10 | 2508 | 2214 | 4690 |
| NvB/SvN | June-Aug.'80 | 7 | 16 | 22 | 3172 | 2958 | 6396 |

Standard, series 1 HCB: var. coeff. 45, n=5 DCB: var. coeff. 42%, n=10

Standard, series 2 HCB: var. coeff. 52% n=7 DCB: var. coeff. 30%, n=10

Table 2 Concentrations of HCB and total PCB in soft tissue homogenates of M.edulis from the Eastern and Western Scheldt in the period 1979-1981. Based on total lipid content in $\mu g.g^{-1}$.

| Eastern Scheldt | | | | | | Western Scheldt | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duursma et al. (1984) | | | | | | Duursma et al. (1984) | | | | | | De Kock & Marquenie (1981) | |
| HCB | | | PCB | | | HCB | | | PCB | | | HCB | PCB |
| $\bar{x}$ | s | n | $\bar{x}$ | s | n | $\bar{x}$ | s | n | $\bar{x}$ | s | n | $\bar{x}$ | $\bar{x}$ |
| 0.09 | 0.13 | 39 | 11.1 | 9.9 | 39 | 0.13 | 0.07 | 13 | 28.0 | 9.2 | 13 | 1) 0.08 | 70.0 |
| | | | | | | | | | | | | 2) 0.05 | 30.4 |

Locations: Colijnsplaat, Wemeldinge, Yerseke

Location: Hoedekenskerke

1) Location: Hoek van Baarland (Winter)
2) Location: Middelgat-Everingen (Summer)

$\bar{x}$ = mean
s = standard deviation
n = number of observations

Table 3 Range of Cd and Hg concentrations found in three bivalve mollusc species applied as monitor organisms in Eastern and Western Scheldt. Concentrations in $\mu g.g^{-1}$ ash-free dry weight.

| | Cd | | Hg | |
|---|---|---|---|---|
| | Eastern Sch. | Western Sch. | Eastern Scheldt | Western Scheldt |
| Mytilus edulis<br>3-3.5 cm<br>littoral<br>1971-1973 | - | - | 0.17-1.7 (mean 0.85) | 0.25-3.0 (mean 0.88) |
| Macoma balthica<br>1-2 cm<br>littoral<br>1978-1979 | 0.12-0.18 | 1.67-2.74 | 0.47-0.94 | 0.39-0.48 |
| Scrobicularia plana<br>2-4 cm<br>littoral<br>1978-1979 | 0.68-1.72 | 1.83-11.71 | 0.43-0.94 | 0.41-0.74 |

Table 4 Sampling scheme of the accumulation - elimination transplantation experiment.

| | data | accumulation series (Perkpolder) | elimination series (Kats) | period of exposure (days) |
|---|---|---|---|---|
| series 1 | 5.4.83 | sample 1 | 1 | 0 |
| | 6.6.83 (day) | 2 | 2 | 62 |
| | 6-7.6.83 (night) | 3 | 3 | 62.5 |
| | 7.6.83 | 4 | 4 | 63 |
| | 8.6.83 | 5 | 5 | 64 |
| | 10.6.83 | 6 | 6 | 66 |
| | 17.6.83 | 7 | 7 | 73 |
| | 6.7.83 | lost | 8 | 92 |
| | 5.8.83 | lost | 9 | 122 |
| series 2 | 11.5.83 | sample 1 | 1 | 0 |
| | 6.6.83 (day) | 2 | 2 | 26 |
| | 6-7.6.83 (night) | not taken | not taken | -- |
| | 7.6.83 | 3 | 3 | 27 |
| | 8.6.83 | 4 | 4 | 28 |
| | 10.6.83 | 5 | 5 | 30 |
| | 17.6.83 | 6 | 6 | 37 |
| | 6.7.83 | 7 | 7 | 56 |
| | 5.8.83 | 8 | 8 | 86 |
| series 3 | 6.6.83(day) | sample 1 | 1 | 0 |
| | 6-7.6.83(night) | 2 | 2 | 0.5 |
| | 7.6.83 | 3 | 3 | 1 |
| | 8.6.83 | 4 | 4 | 2 |
| | 10.6.83 | 5 | 5 | 4 |
| | 17.6.83 | 6 | 6 | 11 |
| | 6.7.83 | 7 | 7 | 30 |
| | 5.8.83 | 8 | 8 | 60 |
| Control | Eastern Scheldt 5.8.83 | not transplanted | | 122 |

Table 5 Statistics of standard homogenate analyses

| Toxicant | n | $\bar{x}$ µg/kg wet weight | Coefficient of variation ($\frac{100\ s}{\bar{x}}$ in %) |
|---|---|---|---|
| Cadmium | 5 | 220 | 14.5 |
| Hg | 5 | 26.2 | 6.1 |
| HCB | 8 | 3.3 | 6.1 |
| PCB-28 | 8 | 5.9 | 6.8 |
| PCB-49 | 8 | 6.2 | 4.8 |
| PCB-52 | 8 | 8.5 | 3.5 |
| PCB-70 | 8 | 11.3 | 4.4 |
| PCB-87 | 8 | 9.1 | 6.6 |
| PCB-101 | 8 | 23.0 | 3.5 |
| PCB-138 | 8 | 28.0 | 4.3 |
| PCB-153 | 8 | 37.3 | 3.5 |
| PCB-180 | 8 | 4.4 | 11.4 |
| p,p-DDE | 8 | 6.8 | 44.1 |

Table 6a Concentrations toxicants in ug/kg$^{-1}$ ash-free dry weight (accumulation)

| | time in days | Cadmium | Hg | HCB | PCB-isomeren 28 | 49 | 52 | 70 | 87 | 101 | 138 | 153 | 180 | p,p-DDE | ashfree-dryweight /animal mg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| series 1 | 0.0 | 2078 | 562 | 16 | 22 | < 32 | 31 | 28 | 37 | 94 | 130 | 200 | 31 | 33 | 214.4 |
| | 62.0 | 6557 | 570 | 16 | 33 | 55 | 110 | 57 | 76 | 200 | 210 | 290 | 26 | 50 | 183.9 |
| | 62.5 | 6876 | 689 | 20 | 33 | 51 | 100 | 51 | 70 | 190 | 200 | 280 | 73 | 46 | 167.8 |
| | 63.0 | 7989 | 617 | 21 | 32 | 50 | 100 | 48 | 71 | 190 | 200 | 290 | 70 | 48 | 177.1 |
| | 64.0 | 7895 | 654 | 10 | 27 | 42 | 81 | 42 | 61 | 170 | 160 | 240 | 63 | 42 | 187.3 |
| | 66.0 | 6113 | 577 | 8 | 31 | 43 | 84 | 45 | 62 | 160 | 170 | 230 | 64 | 42 | 188.2 |
| | 73.0 | 6389 | 531 | 8 | 32 | 43 | 85 | 46 | 63 | 170 | 170 | 240 | 69 | 41 | 195.9 |
| series 2 | 0.0 | 2149 | 420 | 9 | < 21 | < 28 | 19 | < 33 | < 34 | 48 | 71 | 110 | < 32 | < 27 | 254.0 |
| | 26.0 | 3569 | 475 | 11 | 35 | 60 | 114 | 59 | 74 | 200 | 180 | 260 | 61 | 51 | 236.5 |
| | 27.0 | 3477 | 631 | 10 | 37 | 63 | 120 | 58 | 78 | 210 | 200 | 290 | 71 | 54 | 235.2 |
| | 28.0 | 3728 | 665 | 16 | 43 | 69 | 131 | 67 | 88 | 230 | 220 | 310 | 79 | 60 | 204.8 |
| | 30.0 | 4170 | 571 | 17 | 39 | 61 | 110 | 56 | 78 | 220 | 200 | 300 | 74 | 55 | 211.5 |
| | 37.0 | 4689 | 540 | 15 | 39 | 60 | 110 | 58 | 79 | 220 | 210 | 300 | 74 | 54 | 221.4 |
| | 56.0 | 5797 | 477 | 15 | 24 | 49 | 95 | 50 | 75 | 210 | 200 | 300 | 60 | 50 | 246.5 |
| | 86.0 | 5326 | 440 | 13 | 30 | 53 | 100 | 57 | 90 | 260 | 260 | 370 | 70 | 61 | 244.1 |
| series 3 | 0.0 | 2535 | 657 | 17 | < 29 | < 41 | < 44 | < 46 | < 49 | 41 | 60 | 105 | < 32 | < 38 | 212.7 |
| | .5 | 1275 | 540 | < 8 | < 18 | < 25 | < 27 | < 29 | < 30 | 45 | 60 | 100 | < 21 | < 23 | 276.7 |
| | 1.0 | 1965 | 495 | 7 | < 22 | < 30 | < 32 | < 34 | < 36 | 34 | 46 | 77 | < 25 | < 28 | 237.7 |
| | 2.0 | 2766 | 635 | 9 | < 25 | < 34 | < 36 | < 39 | < 40 | 46 | 57 | 93 | < 29 | < 31 | 230.1 |
| | 4.0 | 1864 | 558 | 10 | < 26 | < 36 | 38 | < 41 | < 43 | 66 | 71 | 110 | < 28 | < 33 | 240.6 |
| | 11.0 | 2777 | 517 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 269.9 |
| | 30.0 | 3833 | 563 | 13 | 35 | 53 | 104 | 52 | 72 | 200 | 190 | 280 | 56 | 50 | 283.2 |
| | 60.0 | 4393 | 461 | 11 | 19 | 37 | 72 | 40 | 61 | 170 | 180 | 250 | 42 | 45 | 296.7 |

Table 6a cont. Concentrations toxicants in ug/kg$^{-1}$ ash-free dry weight (elimination)

| | time in days | Cadmium | Hg | HCB | PCB-isomeren | | | | | | | | | p,p-DDE | ashfree-dryweight /animal mg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 28 | 49 | 52 | 70 | 87 | 101 | 138 | 153 | 180 | | |
| series 1 | 0.0 | 11039 | 451 | 12 | 39 | 48 | 82 | 65 | 75 | 200 | 240 | 320 | 56 | 53 | 171.2 |
| | 62.0 | 10225 | 460 | < 9 | < 26 | < 41 | < 38 | < 41 | < 43 | 38 | 54 | 92 | < 32 | < 34 | 153.5 |
| | 62.5 | 10026 | 429 | < 7 | < 21 | < 28 | 18 | < 32 | < 33 | 47 | 62 | 100 | < 32 | < 26 | 161.8 |
| | 63.0 | 7540 | 481 | < 9 | < 28 | < 39 | < 41 | < 44 | < 46 | 38 | 47 | 79 | < 43 | < 36 | 171.2 |
| | 64.0 | 8858 | 478 | < 9 | < 29 | < 40 | < 42 | < 46 | < 47 | 35 | 48 | 81 | < 45 | < 37 | 129.2 |
| | 66.0 | 11574 | 647 | < 9 | < 26 | < 35 | < 38 | < 41 | < 43 | 44 | 60 | 100 | < 41 | < 33 | 133.9 |
| | 73.0 | 6176 | 363 | < 9 | < 27 | < 37 | < 40 | < 43 | < 45 | 35 | 49 | 82 | < 43 | < 35 | 178.4 |
| | 92.0 | 10624 | 648 | < 8 | < 27 | < 37 | < 40 | < 42 | < 45 | 38 | 60 | 96 | < 29 | < 35 | 177.9 |
| | 122.0 | 6225 | 515 | 8 | < 25 | < 35 | 18 | < 40 | < 41 | 44 | 60 | 97 | < 27 | 32 | 206.8 |
| series 2 | 0.0 | 20935 | 623 | 8 | 28 | 38 | 74 | 45 | 63 | 170 | 200 | 270 | 62 | 43 | 105.3 |
| | 26.0 | 10283 | 445 | < 9 | < 27 | < 36 | < 39 | < 41 | < 44 | 46 | 74 | 120 | < 41 | < 33 | 172.7 |
| | 27.0 | 8824 | 547 | < 9 | < 28 | < 37 | < 40 | < 43 | < 45 | 52 | 71 | 120 | < 43 | < 35 | 149.2 |
| | 28.0 | 9605 | 460 | 13 | < 31 | < 42 | < 45 | < 48 | < 51 | 49 | 70 | 120 | < 48 | < 40 | 147.6 |
| | 30.0 | 9024 | 448 | 13 | < 27 | < 36 | < 38 | < 41 | < 43 | 52 | 74 | 120 | < 41 | < 34 | 196.9 |
| | 37.0 | 9362 | 552 | < 8 | < 26 | < 36 | < 20 | < 40 | < 42 | 52 | 69 | 110 | < 41 | < 32 | 185.9 |
| | 56.0 | 8942 | 470 | < 8 | < 24 | < 33 | < 34 | < 37 | < 39 | 37 | 54 | 87 | < 37 | < 30 | 217.3 |
| series 3 | 0.0 | 8568 | 306 | 9 | 22 | 39 | 72 | 37 | 51 | 141 | 148 | 203 | 45 | 34 | 180.6 |
| | .5 | 15452 | 489 | 10 | 25 | 45 | 84 | 43 | 61 | 170 | 170 | 240 | 50 | 40 | 166.0 |
| | 1.0 | 12535 | 414 | 9 | 26 | 41 | 80 | 43 | 63 | 176 | 178 | 256 | 53 | 42 | 124.9 |
| | 2.0 | 13471 | 398 | 20 | < 32 | < 38 | 66 | 38 | 52 | 160 | 170 | 250 | 46 | 37 | 120.9 |
| | 4.0 | 13268 | 379 | 12 | < 39 | < 40 | 49 | 31 | 51 | 140 | 150 | 220 | 34 | 39 | 125.1 |
| | 11.0 | 9483 | 414 | 11 | < 27 | < 39 | 25 | < 41 | 25 | 93 | 110 | 170 | < 41 | < 36 | 162.4 |
| | 30.0 | 12199 | 494 | 9 | < 28 | < 39 | 20 | < 44 | < 46 | 57 | 83 | 130 | < 44 | < 36 | 204.9 |
| | 60.0 | 5452 | 385 | 8 | < 22 | < 29 | 20 | < 33 | < 35 | 49 | 64 | 100 | < 33 | < 27 | 260.7 |

Table 6b toxicant content per animal in ngr. (accumulation)

| | time in days | Cadmium | Hg | HCB | PCB-isomeren 28 | 49 | 52 | 70 | 87 | 101 | 138 | 153 | 180 | p,p-DDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| series 1 | 0.0 | 446 | 120 | 3.4 | 4.7 | < 6.9 | 6.6 | 6.0 | 7.9 | 20.2 | 27.9 | 42.9 | 6.6 | 7.1 |
| | 62.0 | 1206 | 105 | 2.9 | 6.1 | 10.1 | 20.2 | 10.5 | 14.0 | 36.8 | 38.6 | 53.3 | 4.8 | 9.2 |
| | 62.5 | 1154 | 116 | 3.4 | 5.5 | 8.6 | 16.8 | 8.6 | 11.7 | 31.9 | 33.6 | 47.0 | 12.2 | 7.7 |
| | 63.0 | 1415 | 109 | 3.7 | 5.7 | 8.9 | 17.7 | 8.5 | 12.6 | 33.6 | 35.4 | 51.4 | 12.4 | 8.5 |
| | 64.0 | 1479 | 122 | 1.9 | 5.1 | 7.9 | 15.2 | 7.9 | 11.4 | 31.8 | 30.0 | 45.0 | 11.8 | 7.9 |
| | 66.0 | 1150 | 109 | 1.5 | 5.8 | 8.1 | 15.8 | 8.5 | 11.7 | 30.1 | 32.0 | 43.3 | 12.0 | 7.9 |
| | 73.0 | 1252 | 104 | 1.6 | 6.3 | 8.4 | 16.7 | 9.0 | 12.3 | 33.3 | 33.3 | 47.0 | 13.5 | 8.0 |
| series 2 | 0.0 | 546 | 107 | 2.3 | < 5.3 | < 7.1 | 4.8 | < 8.4 | < 8.6 | 12.2 | 18.0 | 27.9 | < 8.1 | < 6.9 |
| | 26.0 | 844 | 112 | 2.6 | 8.3 | 14.2 | 27.0 | 14.0 | 17.5 | 47.3 | 42.6 | 61.5 | 14.4 | 12.1 |
| | 27.0 | 818 | 148 | 2.4 | 8.7 | 14.8 | 28.2 | 13.6 | 18.3 | 49.4 | 47.0 | 68.2 | 16.7 | 12.7 |
| | 28.0 | 763 | 136 | 3.3 | 8.8 | 14.1 | 26.8 | 13.7 | 18.0 | 47.1 | 45.1 | 63.5 | 16.2 | 12.3 |
| | 30.0 | 882 | 121 | 3.6 | 8.2 | 12.9 | 23.3 | 11.8 | 16.5 | 46.5 | 42.3 | 63.5 | 15.7 | 11.6 |
| | 37.0 | 1038 | 120 | 3.3 | 8.6 | 13.3 | 24.4 | 12.8 | 17.5 | 48.7 | 46.5 | 66.4 | 16.4 | 12.0 |
| | 56.0 | 1429 | 118 | 3.7 | 5.9 | 12.1 | 23.4 | 12.3 | 18.5 | 51.8 | 49.3 | 74.0 | 14.8 | 12.3 |
| | 86.0 | 1300 | 107 | 3.2 | 7.3 | 12.9 | 24.4 | 13.9 | 22.0 | 63.5 | 63.5 | 90.3 | 17.1 | 14.9 |
| series 3 | 0.0 | 539 | 140 | 3.5 | < 6.3 | < 8.7 | < 9.3 | < 9.8 | < 10.3 | 8.7 | 12.8 | 22.3 | < 6.8 | < 8.2 |
| | .5 | 353 | 149 | < 2.2 | < 5.0 | < 6.9 | < 7.5 | < 8.0 | < 8.3 | 12.5 | 16.6 | 27.7 | < 5.8 | < 6.4 |
| | 1.0 | 467 | 118 | 1.7 | < 5.2 | < 7.1 | < 7.6 | < 8.1 | < 8.6 | 8.1 | 10.9 | 18.3 | < 5.9 | < 6.7 |
| | 2.0 | 636 | 146 | 2.1 | < 5.8 | < 7.8 | < 8.3 | < 9.0 | < 9.2 | 10.6 | 13.1 | 21.4 | < 6.7 | < 7.1 |
| | 4.0 | 448 | 134 | 2.4 | < 6.3 | < 8.7 | 9.1 | < 9.9 | < 10.3 | 15.9 | 17.1 | 26.5 | < 6.7 | < 7.9 |
| | 11.0 | 750 | 140 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 30.0 | 1086 | 159 | 3.7 | 9.9 | 15.0 | 29.5 | 14.7 | 20.4 | 56.6 | 53.8 | 79.3 | 15.9 | 14.2 |
| | 60.0 | 1303 | 137 | 3.3 | 5.6 | 11.0 | 21.4 | 11.9 | 18.1 | 50.4 | 53.4 | 74.2 | 12.5 | 13.4 |

Table 6b cont. toxicant content per animal in ngr. (elimination)

| | time in days | Cadmium | Hg | HCB | PCB-isomeren | | | | | | | | | p.p-DDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 28 | 49 | 52 | 70 | 87 | 101 | 138 | 153 | 180 | |
| series 1 | 0.0 | 1890 | 77 | 2.1 | 6.7 | 8.2 | 14.0 | 11.1 | 12.8 | 34.2 | 41.1 | 54.8 | 9.6 | 9.1 |
| | 62.0 | 1570 | 71 | < 1.4 | < 4.0 | < 6.3 | < 5.8 | < 6.3 | < 6.6 | 5.8 | 8.3 | 14.1 | < 4.9 | < 5.2 |
| | 62.5 | 1622 | 69 | < 1.1 | < 3.4 | < 4.5 | 2.9 | < 5.2 | < 5.3 | 7.6 | 10.0 | 16.2 | < 5.2 | < 4.2 |
| | 63.0 | 1291 | 82 | < 1.5 | < 4.8 | < 6.7 | < 7.0 | < 7.5 | < 7.9 | 6.5 | 8.0 | 13.5 | < 7.4 | < 6.2 |
| | 64.0 | 1144 | 62 | < 1.2 | < 3.7 | < 5.2 | < 5.4 | < 5.9 | < 6.1 | 4.5 | 6.2 | 10.5 | < 5.8 | < 4.8 |
| | 66.0 | 1550 | 87 | < 1.2 | < 3.5 | < 4.7 | < 5.1 | < 5.5 | < 5.8 | 5.9 | 8.0 | 13.4 | < 5.5 | < 4.4 |
| | 73.0 | 1102 | 65 | < 1.6 | < 4.8 | < 6.6 | < 7.1 | < 7.7 | < 8.0 | 6.2 | 8.7 | 14.6 | < 7.7 | < 6.2 |
| | 92.0 | 1890 | 115 | < 1.4 | < 4.8 | < 6.6 | < 7.1 | < 7.5 | < 8.0 | 6.8 | 10.7 | 17.1 | < 5.2 | < 6.2 |
| | 122.0 | 1287 | 107 | 1.7 | < 5.2 | < 7.2 | 3.7 | < 8.3 | < 8.5 | 9.1 | 12.4 | 20.1 | < 5.6 | 6.6 |
| series 2 | 0.0 | 2204 | 66 | 0.9 | 2.9 | 4.0 | 7.8 | 4.7 | 6.6 | 17.9 | 21.1 | 28.4 | 6.5 | 4.5 |
| | 26.0 | 1776 | 77 | < 1.6 | < 4.7 | < 6.2 | < 6.7 | < 7.1 | < 7.6 | 7.9 | 12.8 | 20.7 | < 7.1 | < 5.7 |
| | 27.0 | 1317 | 82 | < 1.3 | < 4.2 | < 5.5 | < 6.0 | < 6.4 | < 6.7 | 7.8 | 10.6 | 17.9 | < 6.4 | < 5.2 |
| | 28.0 | 1418 | 68 | 1.9 | < 4.6 | < 6.2 | < 6.6 | < 7.1 | < 7.5 | 7.2 | 10.3 | 17.7 | < 7.1 | < 5.9 |
| | 30.0 | 1777 | 88 | 2.6 | < 5.3 | < 7.1 | < 7.5 | < 8.1 | < 8.5 | 10.2 | 14.6 | 23.6 | < 8.1 | < 6.7 |
| | 37.0 | 1740 | 103 | < 1.5 | < 4.8 | < 6.7 | < 3.7 | < 7.4 | < 7.8 | 9.7 | 12.8 | 20.4 | < 7.6 | < 5.9 |
| | 56.0 | 1943 | 102 | < 1.7 | < 5.2 | < 7.2 | < 7.4 | < 8.0 | < 8.5 | 8.0 | 11.7 | 18.9 | < 8.0 | < 6.5 |
| series 3 | 0.0 | 1547 | 55 | 1.6 | 4.0 | 7.1 | 13.0 | 6.6 | 9.2 | 25.4 | 26.8 | 36.7 | 8.2 | 6.1 |
| | .5 | 2565 | 81 | 1.7 | 4.2 | 7.5 | 13.9 | 7.1 | 10.1 | 28.2 | 28.2 | 39.8 | 8.3 | 6.6 |
| | 1.0 | 1566 | 52 | 1.2 | 3.2 | 5.1 | 10.0 | 5.4 | 7.9 | 22.0 | 22.2 | 32.0 | 6.6 | 5.2 |
| | 2.0 | 1629 | 48 | 2.4 | < 3.9 | < 4.6 | 8.0 | 4.6 | 6.3 | 19.3 | 20.6 | 30.2 | 5.6 | 4.5 |
| | 4.0 | 1660 | 47 | 1.5 | < 4.9 | < 5.0 | 6.1 | 3.9 | 6.4 | 17.5 | 18.8 | 27.5 | 4.3 | 4.9 |
| | 11.0 | 1540 | 67 | 1.8 | < 4.4 | < 6.3 | 4.1 | < 6.7 | 4.1 | 15.1 | 17.9 | 27.6 | < 6.7 | < 5.8 |
| | 30.0 | 2500 | 101 | 1.9 | < 5.7 | < 8.0 | 4.1 | < 9.0 | < 9.4 | 11.7 | 17.0 | 26.6 | < 9.0 | < 7.4 |
| | 60.0 | 1421 | 100 | 2.1 | < 5.7 | < 7.6 | 5.2 | < 8.6 | < 9.1 | 12.8 | 16.7 | 26.1 | < 8.6 | < 7.0 |

Table 7

Contaminant concentrations and data on weights and numbers of non-transplanted Eastern and Western Scheldt mussel samples.

| | 22.3.83 | 5.4.83 | 11.5.83 | 6.6.83 | 5.8.83 | 27.10.83 |
|---|---|---|---|---|---|---|
| | Western Scheldt Buoy 22 | Experimental samples | | | | Littoral Perkpolder |
| Eastern Scheldt | | | | | | |
| no individuals | | 88 | 98 | 89 | 88 | |
| wet weight g. mussel -1 | | 1,74 | 1,68 | 1,96 | 1,89 | |
| ash-free dry weight mg. mussel | | 214,4 | 254,0 | 212,7 | 276,7 | |
| ash% of wet weight | | 3,99 | 2,49 | 2,76 | 2,22 | |
| Western Scheldt | | | | | | |
| no individuals | 60 | 75 | 68 | 64 | -- | 60 |
| wet weight g. mussel -1 | 0,59 | 1,39 | 1,07 | 1,30 | -- | 1,72 |
| ash-free dry weight mg. mussel | 100,6 | 171,2 | 105,3 | 180,6 | -- | 239,6 |
| ash% of wet weight | 2,31 | 2,02 | 1,75 | 1,88 | -- | 2,63 |
| Cd East S. | -- | 2078 | 2149 | 1980 | 1195 | -- |
| Cd West S. | 10606 | 11039 | 20935 | 10968 | -- | 17921 |
| Hg East S. | -- | 562 | 420 | 513 | 419 | -- |
| Hg West S. | 459 | 451 | 623 | 392 | -- | 598 |
| HCB East S. | -- | 16 | 9 | 13 | 8 | -- |
| HCB West S. | <13 | 12 | 8 | 11 | -- | <9 |
| pp-DDE East S. | -- | 33 | <27 | 30 | <24 | -- |
| pp-DDE West S. | 29 | 53 | 43 | 43 | -- | 39 |
| PCB 28 East S. | -- | 22 | <21 | <23 | <18 | -- |
| PCB 28 Wast S. | <29 | 39 | 28 | 28 | -- | <20 |
| PCB 49 East S. | -- | <32 | <28 | <32 | <25 | -- |
| PCB 49 West S. | 25 | 48 | 38 | 50 | -- | 32 |
| PCB 52 East S. | -- | 31 | 19 | <34 | 19 | -- |
| PCB 52 West S. | 41 | 82 | 74 | 92 | -- | 57 |
| PCB 70 East S. | -- | 28 | <33 | <36 | <40 | -- |
| PCB 70 West S. | 38 | 65 | 45 | 47 | -- | 36 |
| PCB 87 East S. | -- | <37 | <34 | <38 | <31 | -- |
| PCB 87 West S. | 42 | 75 | 63 | 65 | -- | 57 |
| PCB 101 East S. | -- | 94 | 48 | 32 | 44 | -- |
| PCB 101 West S. | 120 | 200 | 170 | 180 | -- | 160 |
| PCB 138 East S. | -- | 130 | 71 | 47 | 61 | -- |
| PCB 138 West S. | 140 | 240 | 200 | 190 | -- | 180 |
| PCB 153 East S. | -- | 200 | 110 | 82 | 98 | -- |
| PCB 153 West S. | 190 | 320 | 270 | 260 | -- | 260 |
| PCB 180 East S. | -- | 31 | <32 | <25 | <24 | -- |
| PCB 180 West S. | 42 | 56 | 62 | 58 | -- | 54 |

Table 8($a_1$)

Estimated values (y) of $Q_E$, $Q_W$ and $\tau$ with their 95% confidence intervals (+ or - 2 standard deviations s).
$\tau$ accumulation = $\tau$ elimination. All series combined.

| | Y ($\mu g, kg^{-1}$ ash free dry weight) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_E$ | - | - | - | - |
| $Q_W$ | - | - | - | - |
| $\tau$ (days) | - | - | - | - |
| PCB 101 | | | | |
| $Q_E$ | 40.67 | 4.45 | 31.78 | 49.56 |
| $Q_W$ | 197.40 | 4.53 | 188.34 | 206.46 |
| $\tau$ (days) | 9.39 | 1.55 | 6.29 | 12.49 |
| PCB 138 | | | | |
| $Q_E$ | 57.59 | 4.69 | 48.21 | 66.97 |
| $Q_W$ | 200.10 | 4.74 | 190.61 | 209.59 |
| $\tau$ (days) | 11.66 | 1.94 | 7.77 | 15.55 |
| PCB 153 | | | | |
| $Q_E$ | 95.92 | 6.68 | 82.56 | 109.28 |
| $Q_W$ | 283.90 | 6.76 | 270.39 | 299.41 |
| $\tau$ (days) | 11.70 | 2.10 | 7.50 | 15.90 |

Remark: The model did not result in a reasonable fit for Cd. The explanation is to be found in the large difference in final end concentrations of the elimination series and initial concentrations of the accumulation series. With concentrations converted into contents, the fit is better (see Table 8($a_2$).

Table 8($a_2$)

Estimated values (y) of $Q_E$, $Q_W$ and $\tau$ with their 95% confidence intervals (+ or - 2 standard deviations s).
$\tau$ accumulation = $\tau$ elimination. All series combined.

| | Y (ng. individual$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_E$ | 630.00 | 74.80 | 480.40 | 779.60 |
| $Q_W$ | 1985.00 | 76.40 | 1832.20 | 2137.80 |
| $\tau$ (days) | 125.60 | 17.60 | 90.40 | 160.80 |
| PCB 101 | | | | |
| $Q_E$ | 7.95 | 1.78 | 4.39 | 11.51 |
| $Q_W$ | 39.12 | 1.86 | 35.40 | 42.84 |
| $\tau$ (days) | 4.81 | 1.76 | 1.29 | 8.33 |
| PCB 138 | | | | |
| $Q_E$ | 11.56 | 1.70 | 8.16 | 14.96 |
| $Q_W$ | 39.00 | 1.78 | 35.44 | 42.56 |
| $\tau$ (days) | 4.76 | 1.89 | 0.98 | 8.54 |
| PCB 153 | | | | |
| $Q_E$ | 19.04 | 2.51 | 14.02 | 24.06 |
| $Q_W$ | 55.60 | 2.62 | 50.36 | 60.84 |
| $\tau$ (days) | 4.44 | 1.92 | 0.60 | 8.28 |

Remark: Taking the average weight of mussels in the Eastern Scheldt (239.45 mg., p.12) and in the Western Scheldt (159.46 mg., p.12) $Q_E$ and $Q_W$ can be converted back into concentrations for Cadmium:
$Q_E$ = 2.01 - 3.26 $\mu g.g^{-1}$ ash-free dry weight
$Q_W$ = 11.49 - 13.41 $\mu g.g^{-1}$ ash-free dry weight

Table 8($b_1$)

Estimated values (y) of $Q_o$, A and $\tau$ with their 95% confidence interval (+ or - 2s) for the separate accumulation and elimination processes. The model is applied to the difference of contaminant content between series 1 and 3 and series 2 and 3 (see text).

| Accumulation | Y (ng. individual$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | - | - | - | - |
| A | - | - | - | - |
| $\tau$ (days) | - | - | - | - |
| PCB 101 | | | | |
| $Q_o$ | (-14.59) | < 0.001 | (-14.59) | (-14.59) |
| A | 51.73 | < 0.001 | 51.73 | 51.73 |
| $\tau$ (days) | 14.99 | < 0.001 | 14.99 | 14.99 |
| PCB 138 | | | | |
| $Q_o$ | (-15.00) | < 0.001 | (-15.00) | (-15.00) |
| A | 50.00 | < 0.001 | 50.00 | 50.00 |
| $\tau$ (days) | 15.00 | < 0.001 | 15.00 | 15.00 |
| PCB 153 | | | | |
| $Q_o$ | (-9.27) | 1.06 | (-10.33) | (-8.21) |
| A | 51.69 | 1.73 | 49.96 | 53.42 |
| $\tau$ (days) | 12.47 | 0.01 | 12.46 | 12.48 |

Table 8($b_1$, continued)

| Elimination | Y (ng. mussel$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | - | - | - | - |
| A | - | - | - | - |
| $\tau$ (days) | - | - | - | - |
| PCB 101 | | | | |
| $Q_o$ | 3.24 | 1.32 | 1.92 | 4.56 |
| A | 15.43 | 2.37 | 13.06 | 17.79 |
| $\tau$ (days) | 4.54 | 0.09 | 4.89 | 5.07 |
| PCB 138 | | | | |
| $Q_o$ | 4.54 | 1.45 | 3.09 | 5.99 |
| A | 12.22 | 2.83 | 9.38 | 15.05 |
| $\tau$ (days) | 4.03 | 0.16 | 3.86 | 4.19 |
| PCB 153 | | | | |
| $Q_o$ | 6.70 | 1.39 | 5.31 | 8.09 |
| A | 13.25 | 2.61 | 10.64 | 15.86 |
| $\tau$ (days) | 5.15 | 0.12 | 5.03 | 5.26 |

Table 8($b_2$)

Estimated values (y) of $Q_o$, A and $\tau$ with their 95% confidence interval (+ or - 2s) for the separate accumulation and elimination processes. Concentration data of series 1, 2 and 3 combined.

| Accumulation | Y ($\mu g.\ kg^{-1}$ ash free dry weight) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 1891.54 | 558.52 | 1333.02 | 2450.06 |
| A | 8099.25 | 2328.44 | 5770.81 | 10427.68 |
| $\tau$ (days) | 85.00 | 0.01 | 85.00 | 85.01 |
| PCB 101 | | | | |
| $Q_o$ | 40.81 | 28.34 | 12.47 | 69.15 |
| A | 160.65 | 31.34 | 129.31 | 191.99 |
| $\tau$ (days) | 9.60 | 0.11 | 9.49 | 9.70 |
| PCB 138 | | | | |
| $Q_o$ | 63.32 | 26.92 | 36.40 | 90.23 |
| A | 138.06 | 31.64 | 106.42 | 169.71 |
| $\tau$ (days) | 12.01 | 0.09 | 11.92 | 12.10 |
| PCB 153 | | | | |
| $Q_o$ | 103.88 | 39.42 | 64.46 | 143.30 |
| A | 183.50 | 45.71 | 137.79 | 229.22 |
| $\tau$ (days) | 11.51 | 0.10 | 11.41 | 11.61 |

Table 8($b_2$, continued)

| Elimination | | Y | 2S | Y-2S | Y+2S |
|---|---|---|---|---|---|
| | | ($\mu g.\ kg^{-1}$ ash free dry weight) | | | |
| Cadmium | | | | | |
| | $Q_o$ | 8420.47 | 1859.73 | 6560.74 | 10280.19 |
| | A | 5320.96 | 2555.70 | 2765.26 | 7876.66 |
| | $\tau$ (days) | 20.00 | 0.07 | 19.93 | 20.07 |
| PCB 101 | | | | | |
| | $Q_o$ | 39.13 | 6.24 | 32.89 | 45.37 |
| | A | 130.39 | 10.42 | 119.97 | 140.81 |
| | $\tau$ (days) | 11.99 | 0.02 | 11.96 | 12.01 |
| PCB 138 | | | | | |
| | $Q_o$ | 56.53 | 9.18 | 47.35 | 65.72 |
| | A | 133.26 | 15.10 | 118.16 | 148.36 |
| | $\tau$ (days) | 11.99 | 0.04 | 11.95 | 12.02 |
| PCB 153 | | | | | |
| | $Q_o$ | 89.48 | 15.45 | 74.03 | 104.93 |
| | A | 172.03 | 21.36 | 150.67 | 193.39 |
| | $\tau$ (days) | 16.00 | 0.03 | 15.97 | 16.03 |

Table 8($b_3$)

Estimated values (y) of $Q_o$, A and $\tau$ with their 95% confidence interval (+ or - 2s) for the separate accumulation and elimination processes. Content data of series 1, 2 and 3 combined.

| Accumulation | Y (ng. mussel$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 467.20 | 95.61 | 371.59 | 562.81 |
| A | 1203.61 | 464.94 | 738.67 | 1668.55 |
| $\tau$ (days) | 55.00 | 0.01 | 54.99 | 55.02 |
| PCB 101 | | | | |
| $Q_o$ | 9.87 | 9.81 | 0.06 | 19.68 |
| A | 34.24 | 10.63 | 23.62 | 44.87 |
| $\tau$ (days) | 8.03 | 0.21 | 7.82 | 8.23 |
| PCB 138 | | | | |
| $Q_o$ | 15.20 | 9.21 | 5.99 | 24.40 |
| A | 28.48 | 10.07 | 18.41 | 38.56 |
| $\tau$ (days) | 9.06 | 0.21 | 8.85 | 9.27 |
| PCB 153 | | | | |
| $Q_o$ | 25.06 | 13.56 | 11.50 | 38.62 |
| A | 37.54 | 14.77 | 22.77 | 52.31 |
| $\tau$ (days) | 8.75 | 0.24 | 8.50 | 8.99 |

Table 8($b_3$, continued)

| Elimination | Y (ng. mussel$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 1301.21 | 761.94 | 539.27 | 2063.15 |
| A | 564.64 | 746.37 | (-181.73) | 1311.01 |
| $\tau$ (days) | 39.97 | 0.08 | 39.89 | 40.05 |
| PCB 101 | | | | |
| $Q_o$ | 7.61 | 2.14 | 5.47 | 9.75 |
| A | 17.82 | 3.48 | 14.34 | 21.30 |
| $\tau$ (days) | 11.02 | 0.07 | 10.95 | 11.09 |
| PCB 138 | | | | |
| $Q_o$ | 11.02 | 2.26 | 8.76 | 13.27 |
| A | 16.89 | 4.29 | 12.60 | 21.18 |
| $\tau$ (days) | 8.01 | 0.13 | 7.87 | 8.14 |
| PCB 153 | | | | |
| $Q_o$ | 17.82 | 3.41 | 14.41 | 21.23 |
| A | 20.28 | 6.36 | 13.92 | 26.64 |
| $\tau$ (days) | 7.95 | 0.17 | 7.78 | 8.11 |

Table 8($b_4$)

Estimated values (y) of $Q_o$, A and $\tau$ with their 95% confidence interval (+ or - 2s) for the separate accumulation and elimination processes. Series 3 only. $Q_o$ and A in concentrations.

| Accumulation | Y ($\mu g.\ kg^{-1}$ ash free dry weight) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 1968.11 | - | - | - |
| A | 2897.68 | - | - | - |
| $\tau$ (days) | 25.02 | - | - | - |
| PCB 101 | | | | |
| $Q_o$ | 29.84 | 33.42 | -3.58 | 63.26 |
| A | 159.09 | 49.41 | 109.68 | 208.50 |
| $\tau$ (days) | 11.02 | 0.13 | 10.89 | 11.14 |
| PCB 138 | | | | |
| $Q_o$ | 46.57 | 25.80 | 20.77 | 72.37 |
| A | 146.70 | 45.71 | 100.98 | 192.41 |
| $\tau$ (days) | 14.01 | 0.10 | 13.91 | 14.11 |
| PCB 153 | | | | |
| $Q_o$ | 80.31 | 22.05 | 58.26 | 102.35 |
| A | 192.85 | 43.43 | 149.42 | 236.28 |
| $\tau$ (days) | 14.99 | 0.06 | 14.93 | 15.04 |

Table 8($b_4$, continued)

| Elimination | Y ($\mu g.\ kg^{-1}$ ash free dry weight) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 3960.33 | 808.17 | 3157.93 | 4774.28 |
| A | 8858.50 | 952.07 | 7980.93 | 9885.07 |
| $\tau$ (days) | 49.99 | 0.01 | 49.98 | 50.00 |
| PCB 101 | | | | |
| $Q_o$ | 44.80 | 26.80 | 18.00 | 71.60 |
| A | 123.27 | 30.21 | 93.06 | 153.49 |
| $\tau$ (days) | 12.99 | 0.07 | 12.92 | 13.06 |
| PCB 138 | | | | |
| $Q_o$ | 60.83 | 38.92 | 21.91 | 99.76 |
| A | 109.83 | 38.70 | 71.13 | 148.53 |
| $\tau$ (days) | 17.00 | 0.06 | 16.93 | 17.06 |
| PCB 153 | | | | |
| $Q_o$ | 95.95 | 17.52 | 78.43 | 113.47 |
| A | 146.92 | 22.07 | 124.84 | 168.99 |
| $\tau$ (days) | 17.49 | 0.03 | 17.45 | 17.52 |

Table 8($b_5$)

Estimated values (y) of $Q_o$, A and $\tau$ with their 95% confidence interval (+ or - 2s) for the separate accumulation and elimination processes. Serie 3 only. Q and A in contents per animal.

| Accumulation | Y (ng. mussel$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 459.39 | 122.37 | 337.02 | 581.77 |
| A | 1169.11 | 697.46 | 471.56 | 1866.58 |
| $\tau$ (days) | 49.98 | 0.02 | 49.96 | 50.00 |
| PCB 101 | | | | |
| $Q_o$ | 6.45 | 9.02 | -2.57 | 15.48 |
| A | 48.79 | 14.45 | 34.35 | 63.24 |
| $\tau$ (days) | 12.51 | 0.11 | 12.40 | 12.62 |
| PCB 138 | | | | |
| $Q_o$ | 10.58 | 6.39 | 4.19 | 16.97 |
| A | 46.57 | 12.35 | 34.22 | 58.92 |
| $\tau$ (days) | 15.02 | 0.07 | 14.95 | 15.09 |
| PCB 153 | | | | |
| $Q_o$ | 18.29 | 12.59 | 5.69 | 30.88 |
| A | 61.99 | 24.02 | 37.97 | 86.01 |
| $\tau$ (days) | 15.00 | 0.11 | 14.89 | 15.11 |

Table 8($b_5$, continued)

| Elimination | Y (ng. mussel$^{-1}$) | 2S | Y-2S | Y+2S |
|---|---|---|---|---|
| Cadmium | | | | |
| $Q_o$ | 1074.97 | 1327.12 | (-252.16) | 2402.09 |
| A | 709.06 | 1349.94 | (-640.89) | 2059.00 |
| $\tau$ (days) | 48.57 | 0.11 | 48.46 | 48.68 |
| PCB 101 | | | | |
| $Q_o$ | 12.69 | 0.56 | 12.13 | 13.25 |
| A | 13.73 | 0.94 | 12.80 | 14.67 |
| $\tau$ (days) | 4.07 | 0.05 | 4.02 | 4.12 |
| PCB 138 | | | | |
| $Q_o$ | 17.13 | 0.42 | 16.71 | 17.55 |
| A | 10.77 | 0.81 | 9.96 | 11.58 |
| $\tau$ (days) | 2.01 | 0.09 | 1.92 | 2.11 |
| PCB 153 | | | | |
| $Q_o$ | 26.55 | 0.61 | 25.94 | 27.17 |
| A | 11.93 | 1.18 | 10.75 | 13.11 |
| $\tau$ (days) | 2.06 | 0.12 | 1.94 | 2.18 |

Table 9 M. edulis; τ-ranges for Cd, PCB 101, PCB 138 and PCB 153

| | τ-accumulation (days) | | τ-elimination (days) | |
|---|---|---|---|---|
| based on: | concentrations | body burden | concentrations | body burden |
| Cadmium | 25.0-85.0 | 50.0-55.0 | 20.1-50.0 | 40.0-48.6 |
| PCB 101 | 9.60-11.02 | 8.03-14.99 | 11.99-12.99 | 4.07-11.02 |
| PCB 138 | 12.01-14.01 | 9.06-15.02 | 11.99-17.00 | 2.01-8.01 |
| PCB 153 | 11.51-14.99 | 8.75-15.00 | 16.00-17.49 | 2.06-7.95 |

Table 10

Concentrations and body burdens of Cd, PCB 101, 138 and 153 established with various model calculations for the Eastern Scheldt ($Q_E$ or $Q_o$) and the Western Scheldt ($Q_W$ or $Q_o$ + A). The ratio for the two areas (Western Scheldt: Eastern Scheldt) is also given. $\tau$ is presented in days.

Table 10a

| | $Q_E$ (tables a) $Q_o$ (tables b) | $Q_W$ (tables a) $Q_o + A$ (tables b) | $\tau$ | $Q_W:Q_E$ $(Q_o+A):Q_o$ |
|---|---|---|---|---|
| Cadmium (in concentrations, $\mu g.\ kg^{-1}$ ash-free dry) | | | | |
| acc. (b2) | 1892 | 9991 | 85.0 | 5.28 |
| acc. (b4) | 1968 | 4866 | 25.0 | 2.47 |
| el. (b2) | 8420 | 13741 | 20.1 | 1.63 |
| el. (b4) | 3960 | 12819 | 50.0 | 3.24 |
| Range | 1892-8420 | 4866-13741 | acc. 25.0-85.0<br>el. 20.1-50.0 | 1.63-5.28 |
| Cadmium (in contents, $ng.\ mussel^{-1}$) | | | | |
| acc.=el. (a2) | 630 | 1985 | 125.6 | 3.15 |
| acc. (b3) | 467 | 1671 | 55.0 | 3.58 |
| acc. (b5) | 459 | 1629 | 50.0 | 3.55 |
| acc. (b3) | 1301 | 1866 | 40.0 | 1.43 |
| acc. (b5) | 1075 | 1784 | 48.6 | 1.66 |
| Range | 459-1301 | 1629-1985 | acc. 50.0-125.6<br>el. 40.0-125.6 | 1.43-3.58 |

Remark: Clearly, $Q_o$ estimated from the elimination series (Eastern Scheldt) is higher than $Q_o$ estimated from the accumulation series (Western Scheldt). Cd seems to eliminate only with difficulty once it has been taken up by the animal. There is, however, a fraction that then eliminates with a rate constant that is compatible with the rate constant for the accumulation process ($\tau \sim 50$ days).

Table 10b

| | $Q_E$ (tables a) $Q_o$ (tables b) | $Q_W$ (tables a) $Q_o$ + A (tables b) | τ | $Q_W:Q_E$ $(Q_o+A):Q_o$ |
|---|---|---|---|---|
| PCB 101 (in concentrations, µg. $kg^{-1}$ ash-free dry) | | | | |
| acc.=el. (a1) | 40.67 | 197.40 | 9.39 | 4.85 |
| acc. (b2) | 40.81 | 201.46 | 9.60 | 4.94 |
| acc. (b4) | 29.84 | 188.93 | 11.02 | 6.33 |
| el. (b2) | 39.13 | 169.52 | 11.99 | 4.33 |
| el. (b4) | 44.80 | 168.07 | 12.99 | 3.75 |
| Range | 29.84-44.80 | 168.07-201.46 | acc. 9.39-11.02<br>el. 11.99-12.99 | 4.33-6.33 |
| PCB 101 (in contents, ng. $mussel^{-1}$) | | | | |
| acc.=el. (a2) | 7.95 | 39.12 | 4.81 | 4.92 |
| acc. (b1) | * | * | 14.99 | - |
| acc. (b3) | 9.87 | 44.11 | 8.03 | 4.47 |
| acc. (b5) | 6.45 | 55.24 | 12.51 | 8.56 |
| el. (b1) | * | * | 4.98 | - |
| el. (b3) | 7.61 | 25.43 | 11.02 | 3.34 |
| el. (b5) | 12.69 | 26.42 | 4.07 | 2.08 |
| Range | 6.45-12.69 | 25.43-55.24 | acc. 4.81-14.99<br>el. 4.07-11.02 | 2.08-8.56 |

Table 10c

| | $Q_E$ (tables a) $Q_o$ (tables b) | $Q_W$ (tables a) $Q_o + A$ (tables b) | $\tau$ | $Q_W:Q_E$ $(Q_o+A):Q_o$ |
|---|---|---|---|---|
| PCB 138 (in concentrations, $\mu g.\ kg^{-1}$ ash-free dry) | | | | |
| acc.=el. (a1) | 57.59 | 200.10 | 11.66 | 3.47 |
| acc. (b2) | 63.32 | 201.38 | 12.01 | 3.18 |
| acc. (b4) | 46.57 | 193.27 | 14.01 | 4.15 |
| el. (b2) | 56.53 | 189.79 | 11.99 | 3.36 |
| el. (b4) | 60.83 | 170.66 | 17.00 | 2.81 |
| Range | 46.57-63.32 | 170.66-201.38 | acc. 11.66-14.01<br>el. 11.66-17.00 | 2.81-4.15 |
| PCB 138 (in contents, $ng.\ mussel^{-1}$) | | | | |
| acc.=el. (a2) | 11.56 | 39.00 | 4.76 | 3.37 |
| acc. (b1) | * | * | 15.00 | - |
| acc. (b3) | 15.20 | 43.68 | 9.06 | 2.87 |
| acc. (b5) | 10.58 | 57.15 | 15.02 | 5.40 |
| el. (b1) | * | * | 4.03 | - |
| el. (b3) | 11.02 | 27.91 | 8.01 | 2.53 |
| el. (b5) | 17.13 | 27.90 | 2.01 | 1.63 |
| Range | 10.58-17.13 | 27.90-57.15 | acc. 4.76-15.02<br>el. 2.01- 8.01 | 1.63-5.40 |

* = not relevant

Table 10d

| | $Q_E$ (tables a) $Q_o$ (tables b) | $Q_W$ (tables a) $Q_o$ + A (tables b) | τ | $Q_W:Q_E$ $(Q_o+A):Q_o$ |
|---|---|---|---|---|
| PCB 153 (in concentrations, µg. $kg^{-1}$ ash-free dry) | | | | |
| acc.=el. (a1) | 95.92 | 283.90 | 11.70 | 2.96 |
| acc. (b2) | 103.88 | 287.38 | 11.51 | 2.77 |
| acc. (b4) | 80.31 | 273.16 | 14.99 | 3.40 |
| el. (b2) | 89.48 | 261.51 | 16.00 | 2.92 |
| el. (b4) | 95.95 | 242.87 | 17.49 | 2.53 |
| Range | 80.31-103.88 | 242.87-287.38 | acc. 11.51-14.99<br>el. 11.70-17.49 | 2.53-3.40 |
| PCB 153 (in contents, ng. $mussel^{-1}$) | | | | |
| acc.=el. (a2) | 19.04 | 55.60 | 4.44 | 2.92 |
| acc. (b1) | * | * | 12.47 | - |
| acc. (b3) | 25.06 | 62.60 | 8.75 | 2.50 |
| acc. (b5) | 18.29 | 80.28 | 15.00 | 4.39 |
| el. (b1) | * | * | 5.15 | - |
| el. (b3) | 17.82 | 38.10 | 7.95 | 2.14 |
| el. (b5) | 26.55 | 38.48 | 2.06 | 1.45 |
| Range | 17.82-26.55 | 38.10-80.28 | acc. 4.44-15.00<br>el. 2.06- 7.95 | 1.45-4.39 |

* = not relevant

FIGURES 1 - 10

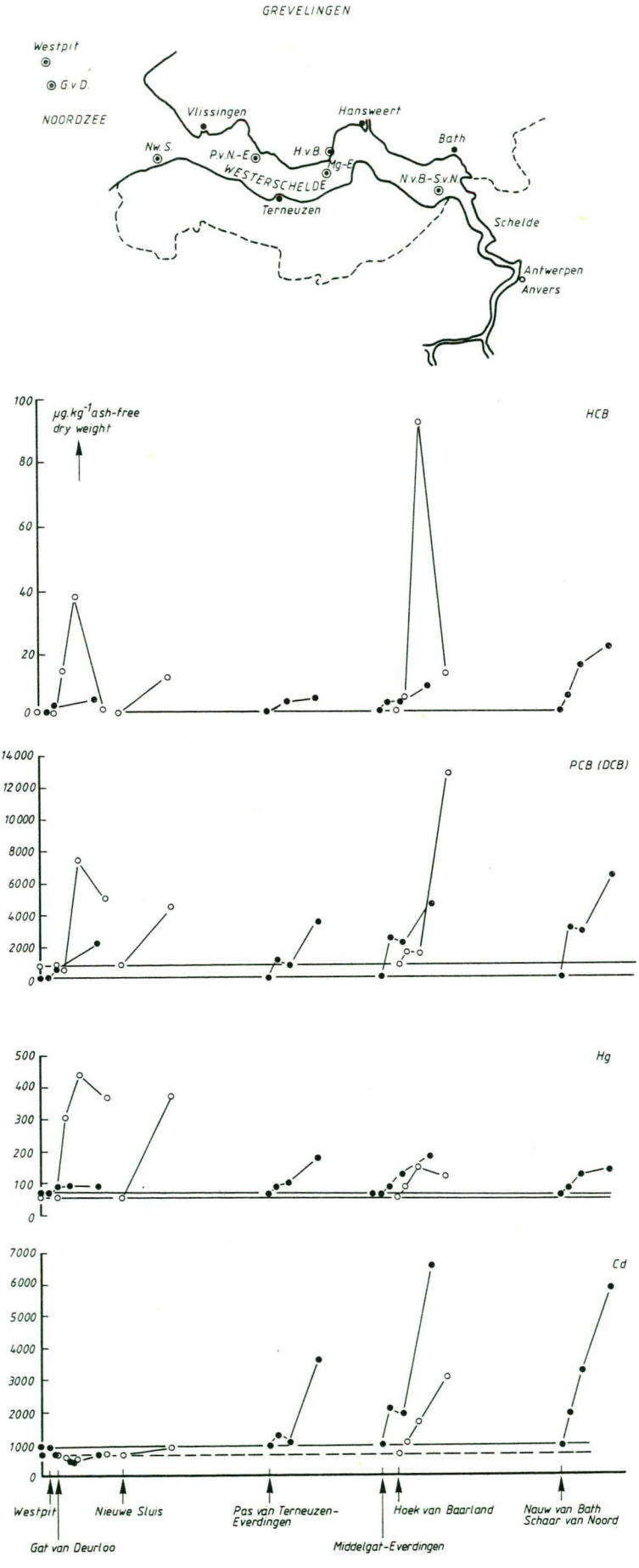
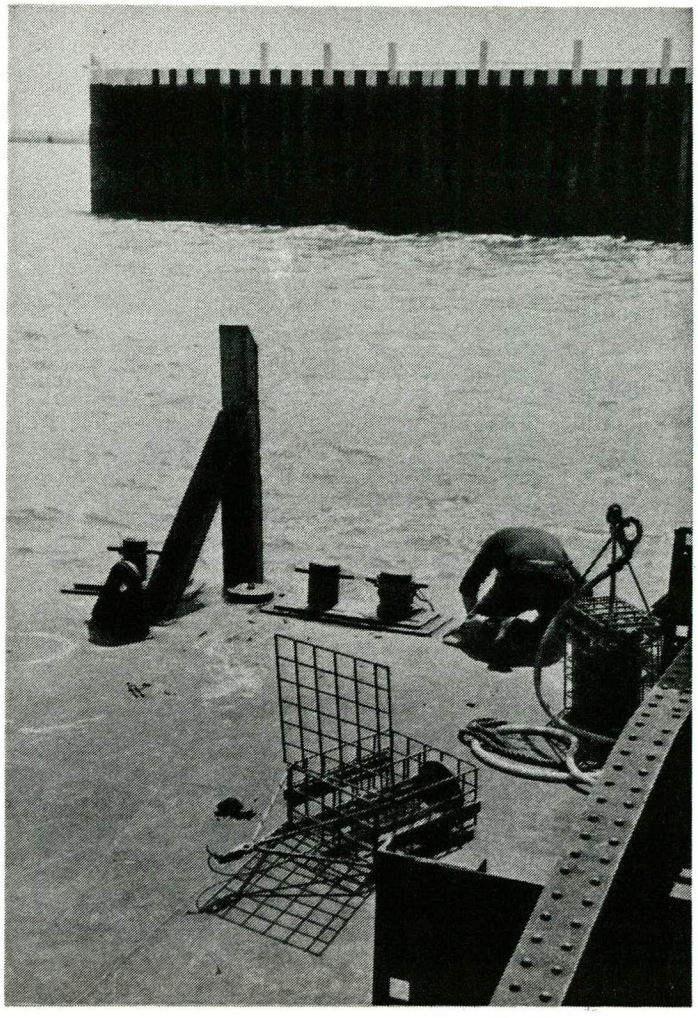



Fig. 1. Map of the Western Scheldt estuary and uptake of contaminants in experimental mussels at different locations in 1979/1980.



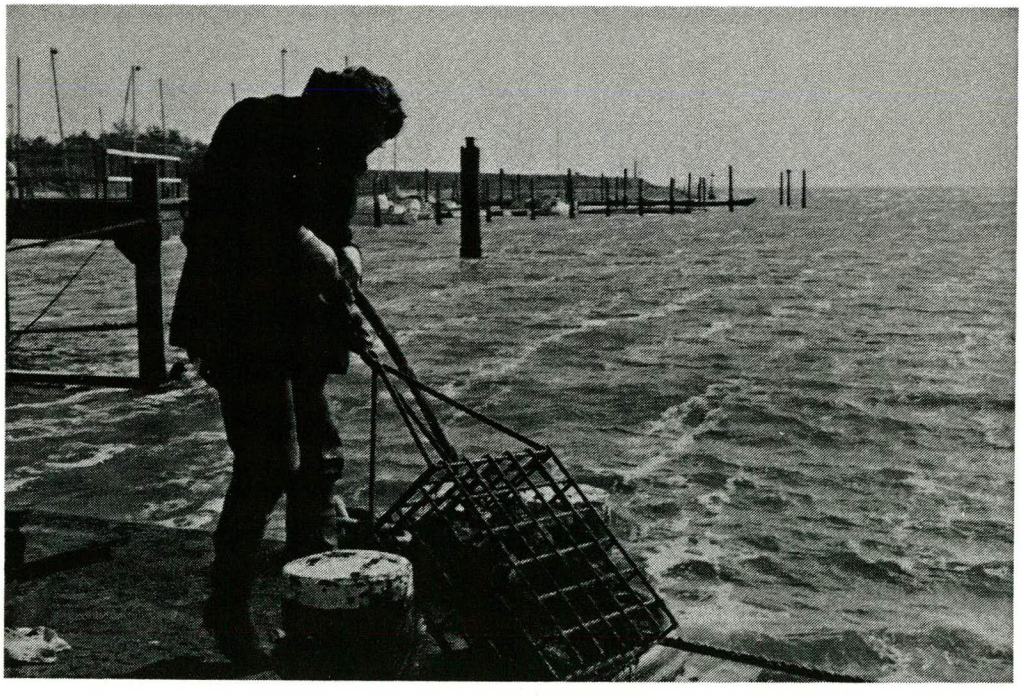


Fig. 2. Sample collection (top: Ferry Harbour Perkpolder; bottem: Kats Harbour).

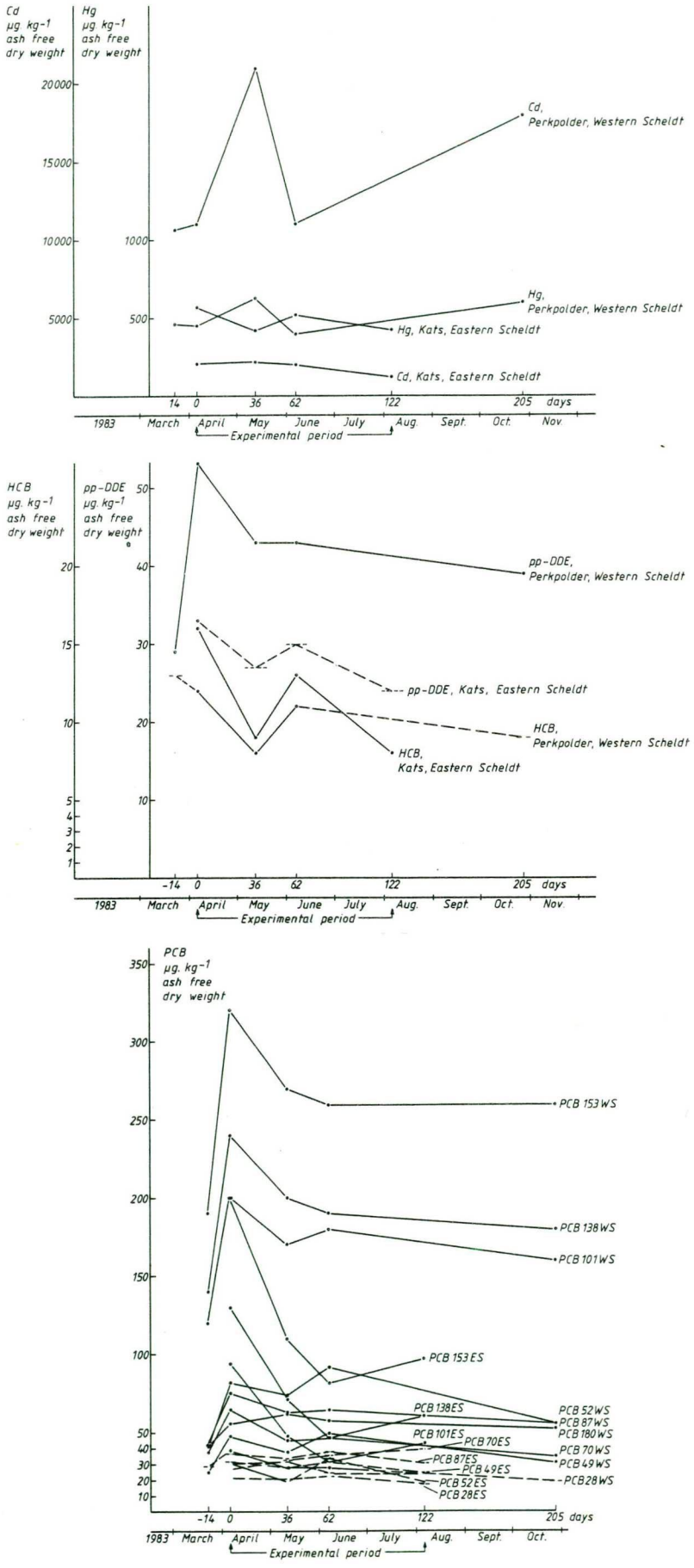



Fig. 3. Concentration of contaminants in experimental mussels.

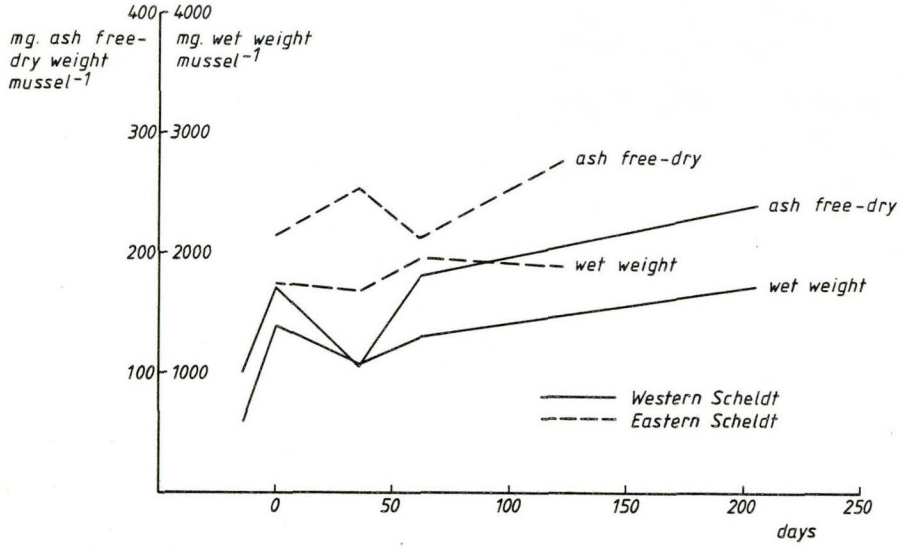



Fig. 4. Charge in weights per mussel during the experimental period.

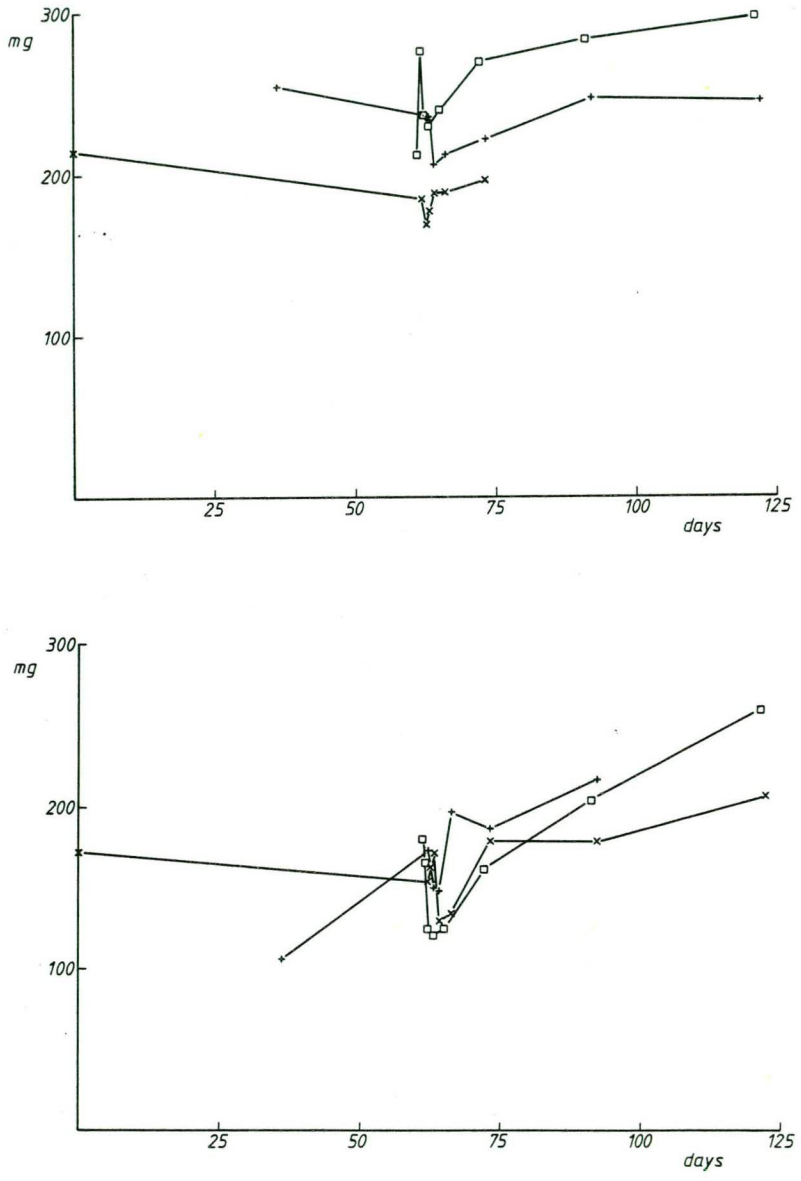



Fig. 5a, b Ash-free dry weight (in mg mussel$^{-1}$) versus time in the accumulation and elimination transplantation series.

x series 1

+ series 2

□ series 3

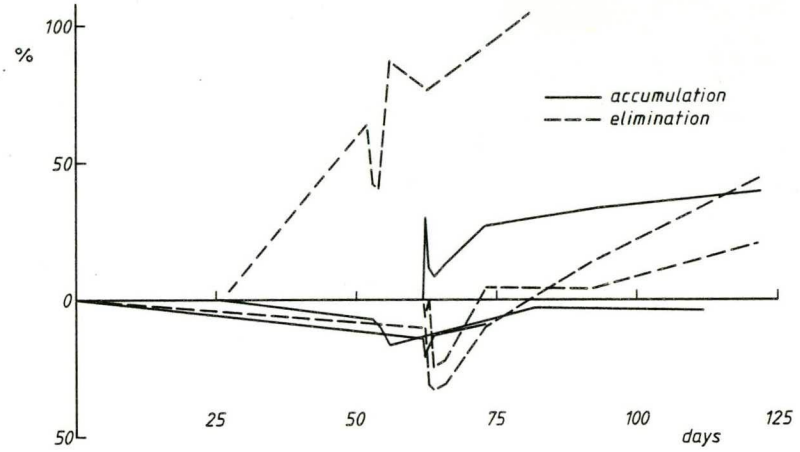



Fig. 6. Growth expressed as a percentage weight relative to the t = 0 sample from each series during the accumulation and elimination experiments.

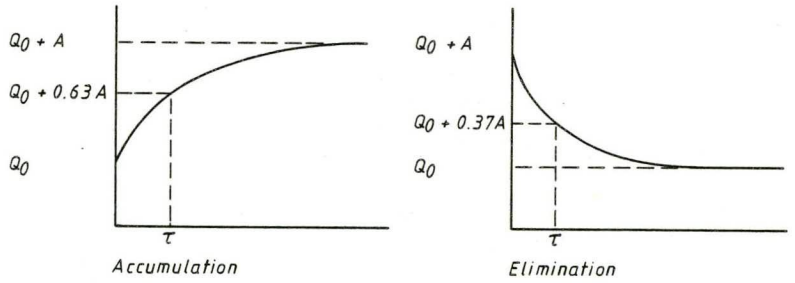
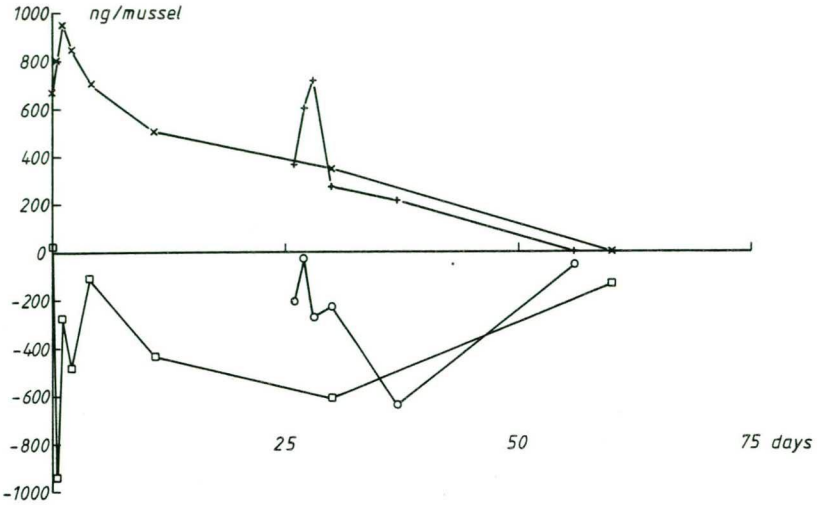



Fig. 7. Accumulation and elimination obeying first order kinetics.



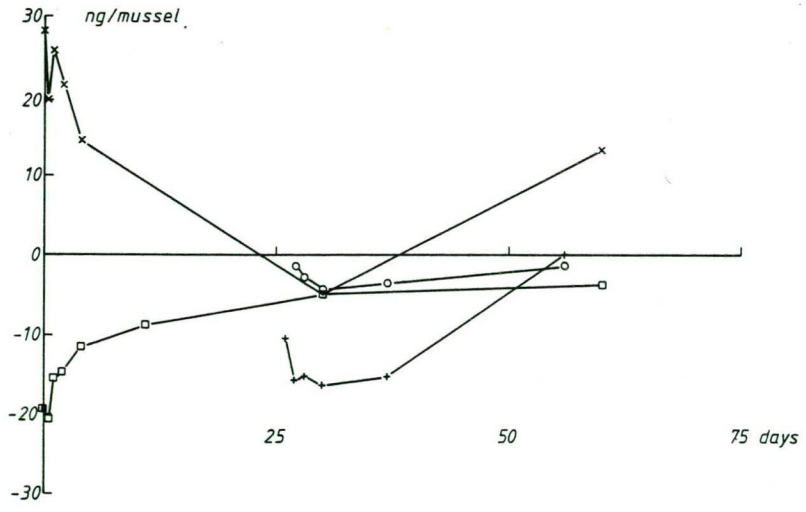

a. Camium

x - x = series 1 - series 3 (acc.)

\+ - + = series 1 - series 2 (acc.)

□ - □ = series 1 - series 3 (eli.)

o - o = series 1 - series 2 (eli.)




b. PCB 101

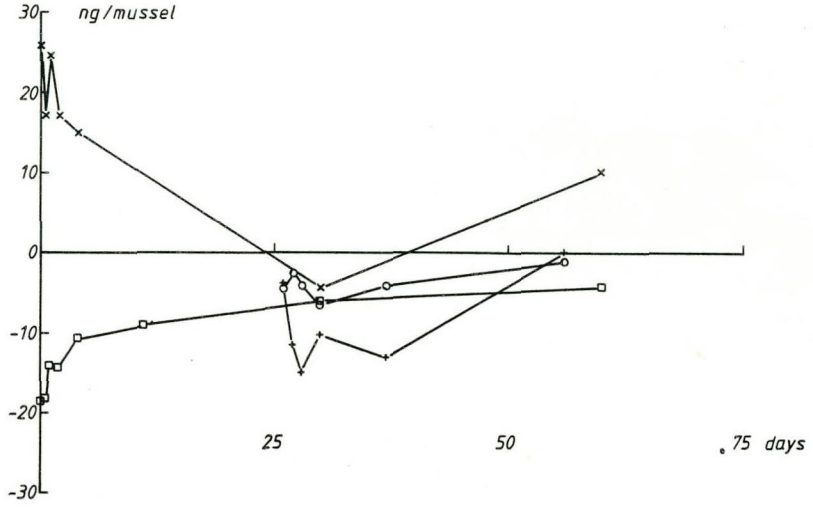
x - x = series 1 - series 3 (acc.)

\+ - + = series 1 - series 2 (acc.)

□ - □ = series 1 - series 3 (eli.)

o - o = series 1 - series 2 (eli.)

Fig. 8a, b Charge in body burder of contaminants during the experimental period (see text).



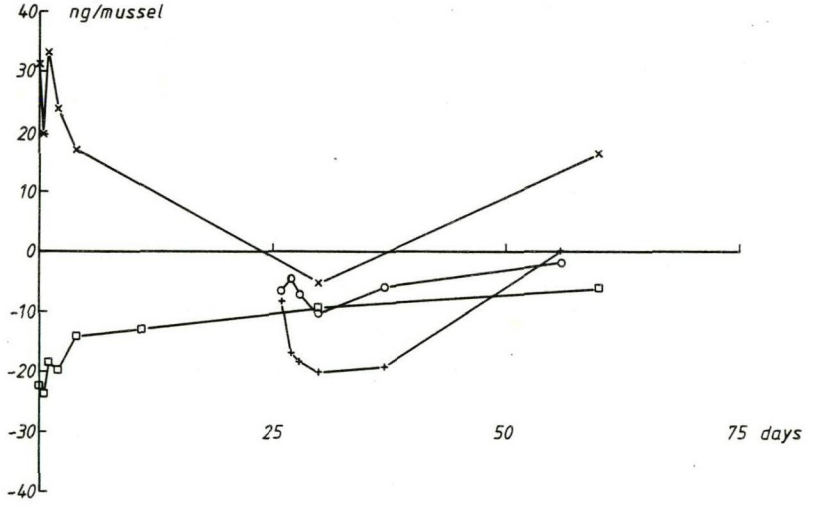

c. PCB 138

x - x = series 1 - series 3 (acc.)

+ - + = series 1 - series 2 (acc.)

□ - □ = series 1 - series 3 (eli.)

o - o = series 1 - series 2 (eli.)




d. PCB 153

x - x = series 1 - series 3 (acc.)

+ - + = series 1 - series 2 (acc.)

□ - □ = series 1 - series 3 (eli.)

o - o = series 1 - series 2 (eli.)

Fig. 8c, d Charge in body burden of contaminants during the experimental period (see text).

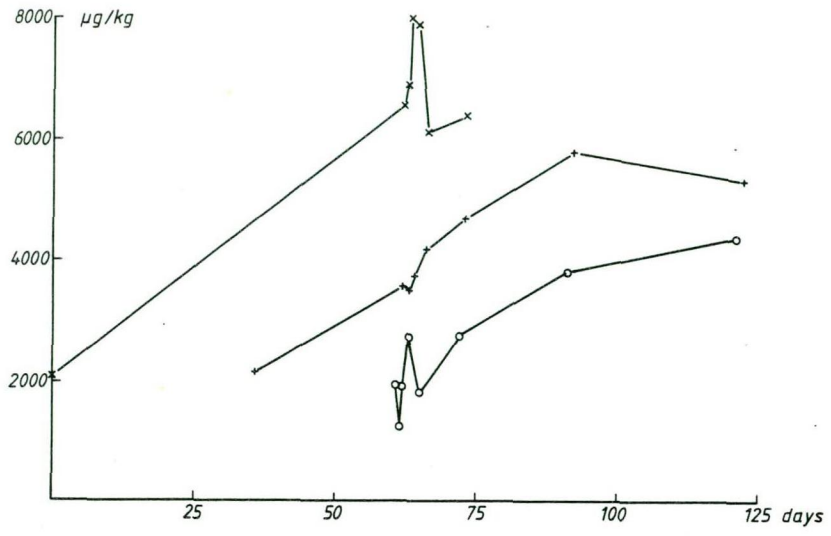



Fig. 9a

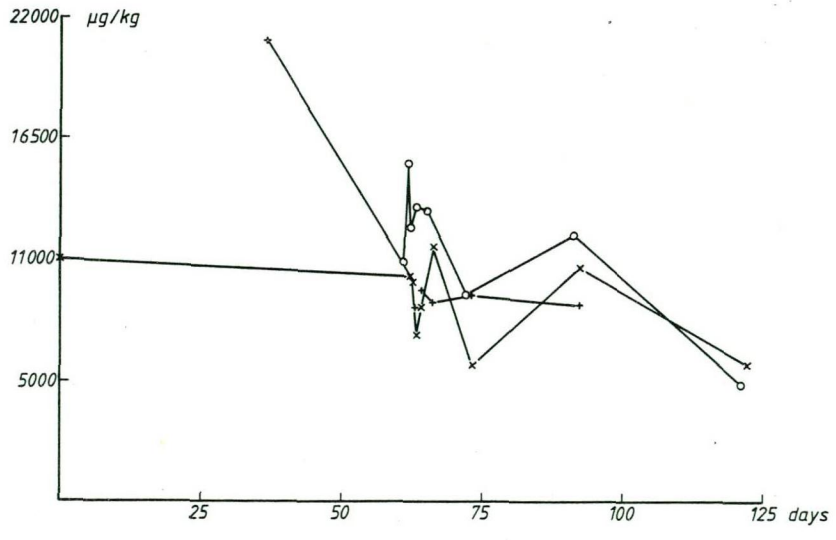



Fig. 9b

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

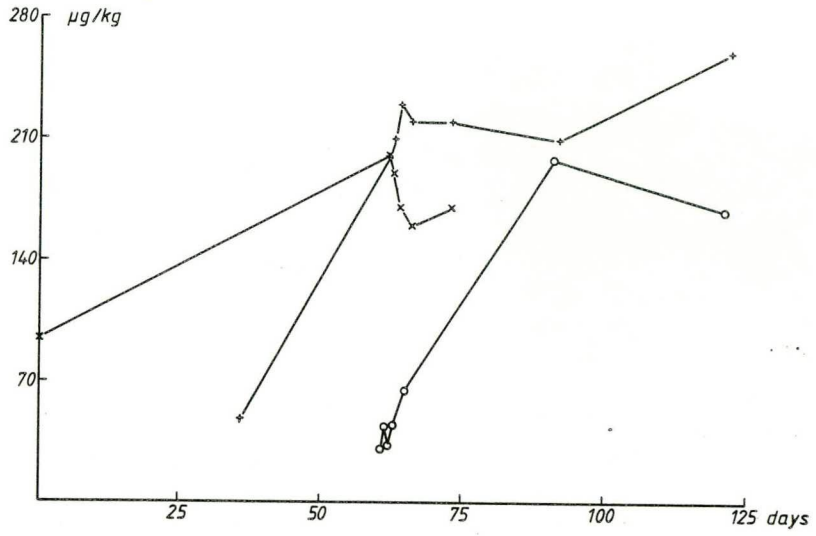



Fig. 9c

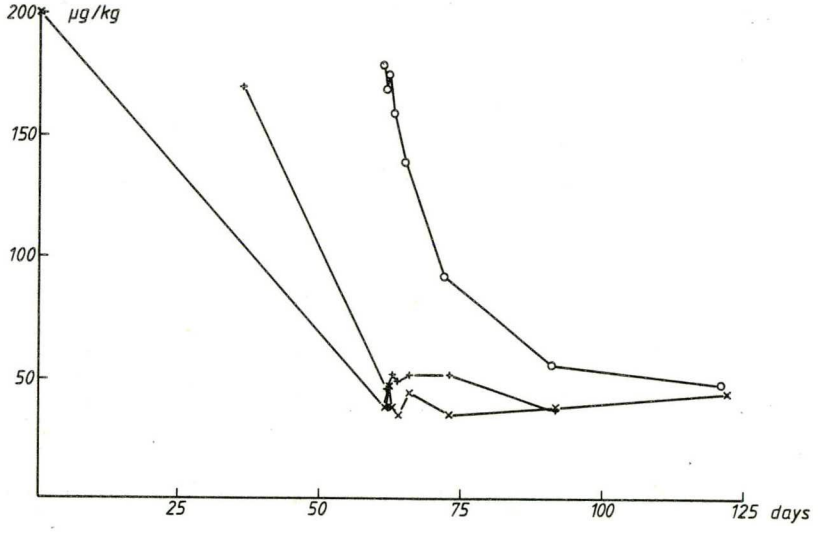



Fig. 9d

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

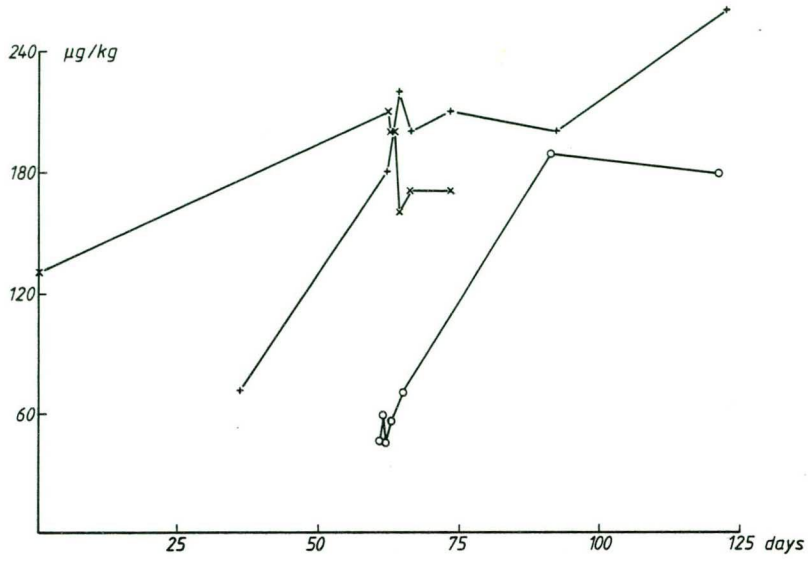



Fig. 9e

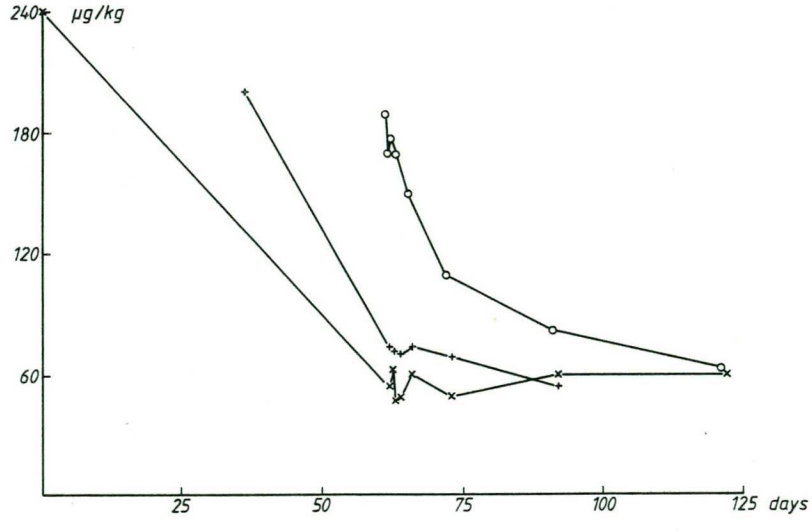



Fig. 9f

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

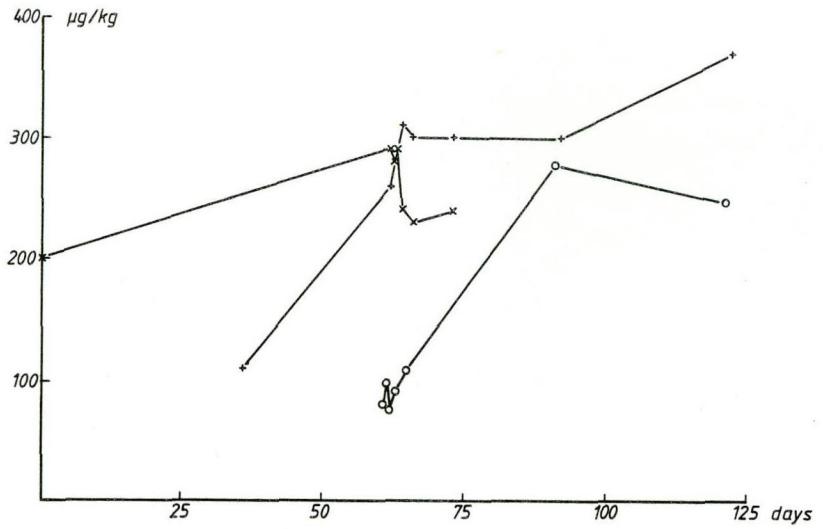



Fig. 9g

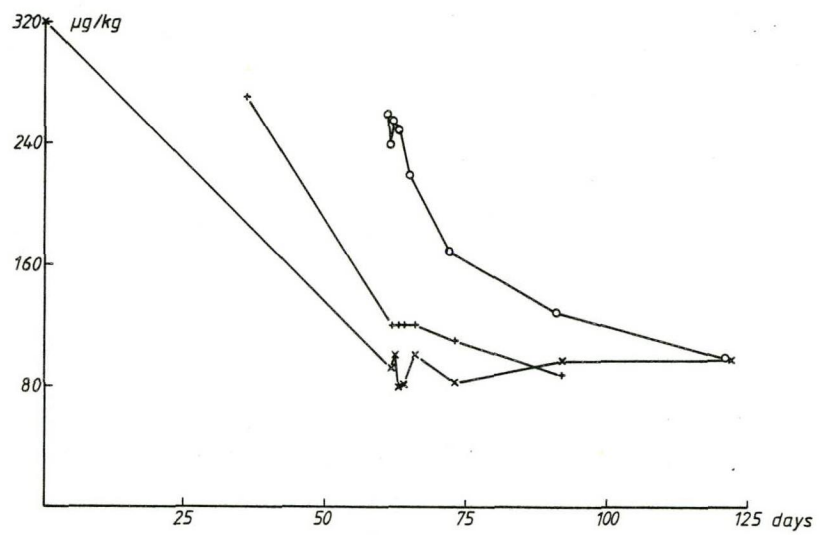



Fig. 9h

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

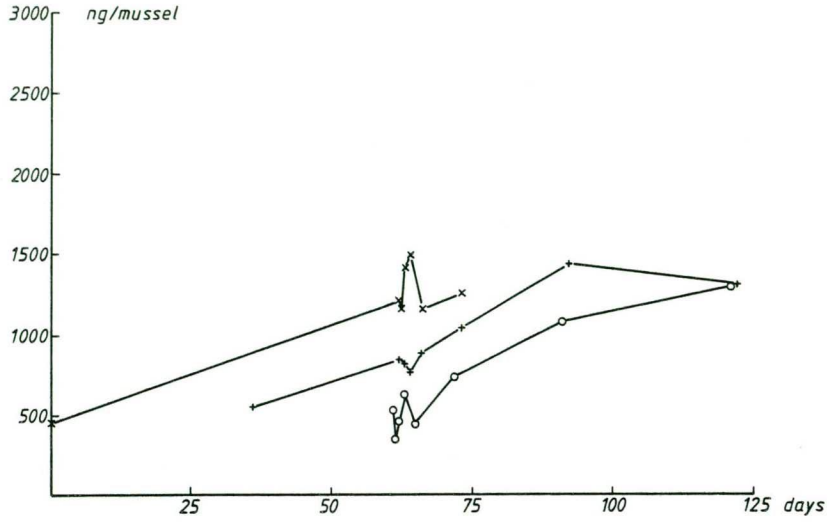



Fig. 9i

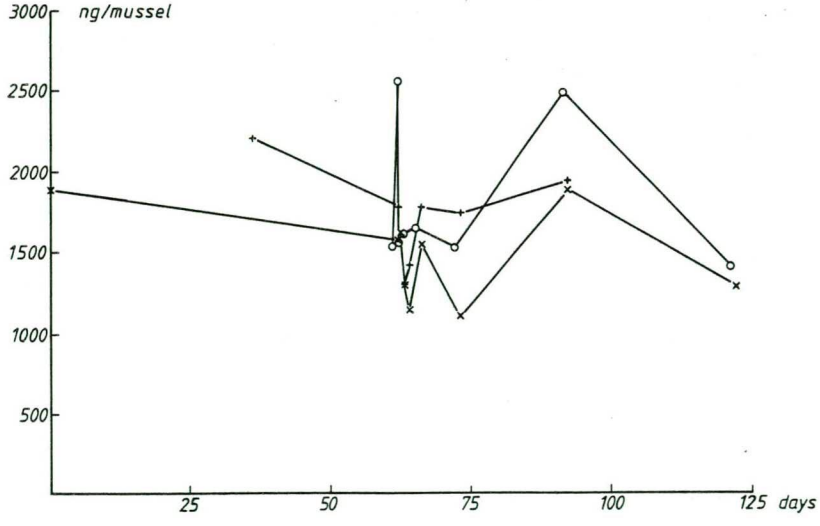



Fig. 9j

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

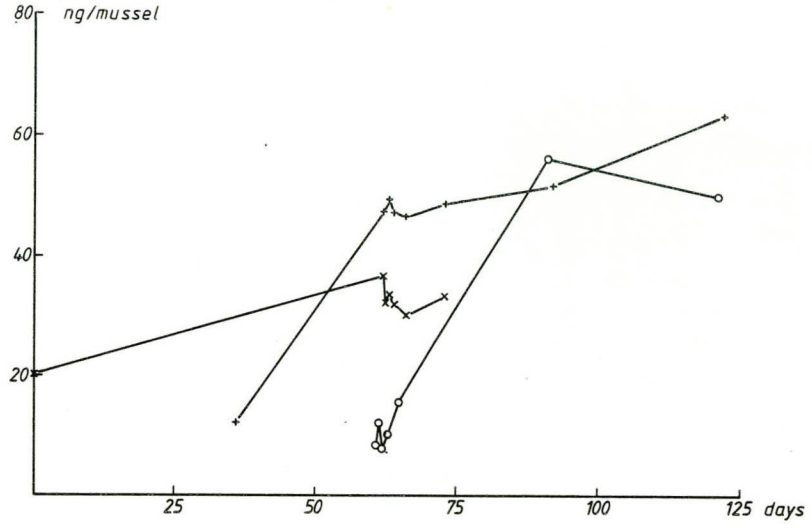



Fig. 9k

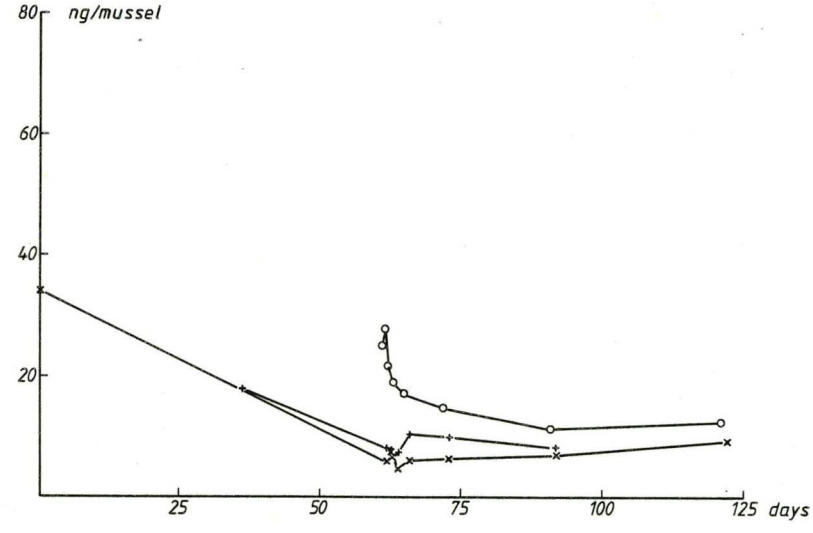



Fig. 9l

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

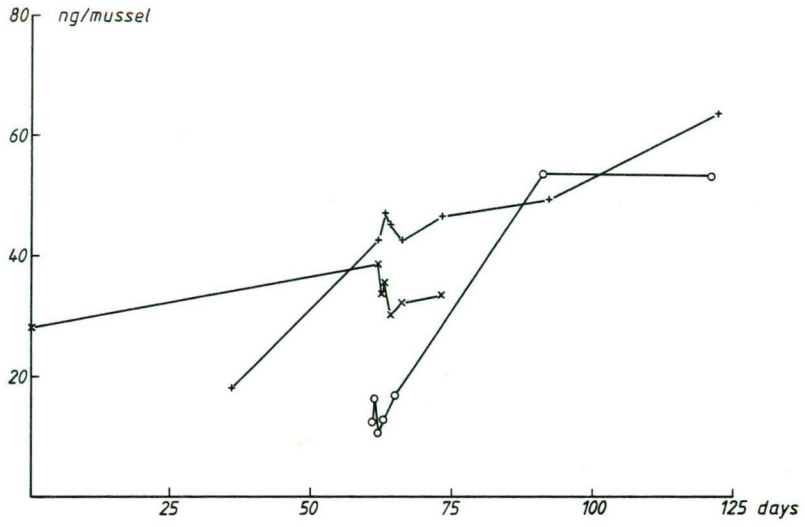



Fig. 9m

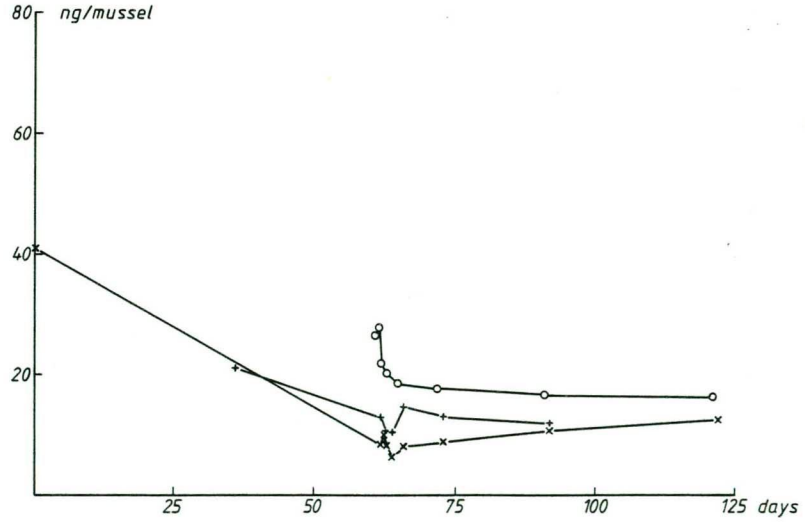



Fig. 9n

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

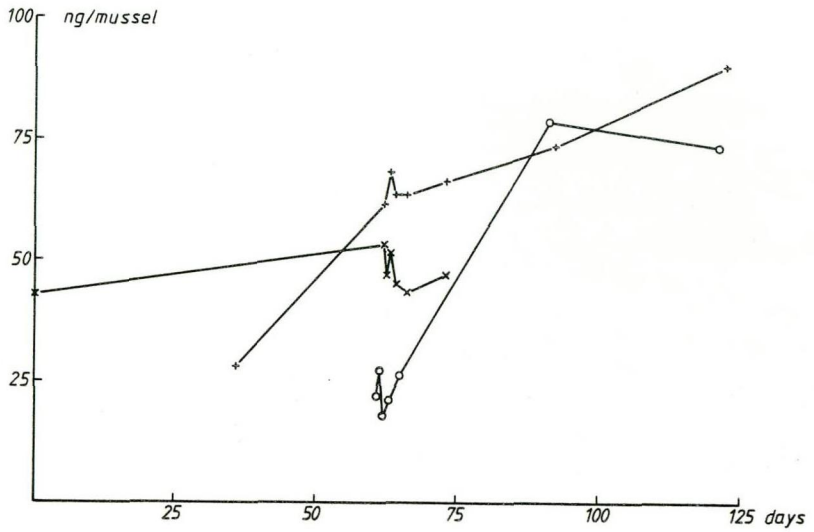



Fig. 9o

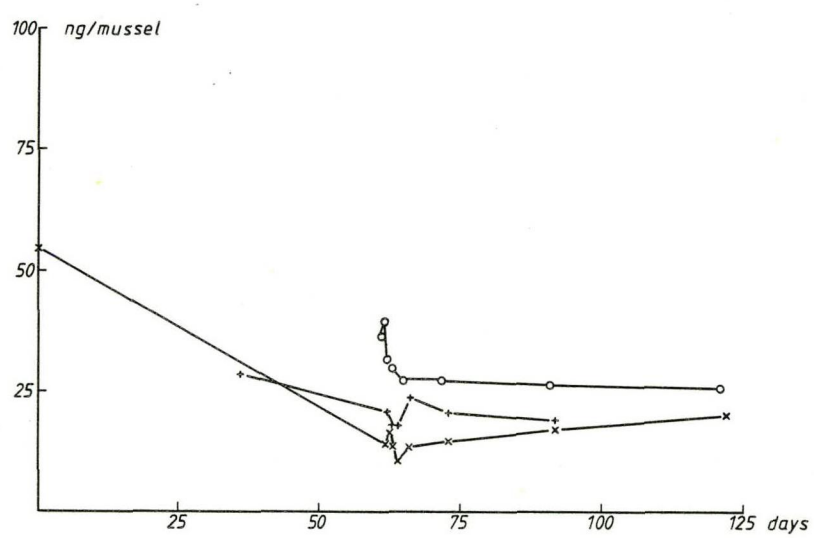



Fig. 9p

Fig. 9. Accumulation and elimination of contaminants in experimental mussels.

| Cd | PCB 101 | PCB 138 | PCB 153 | | |
|---|---|---|---|---|---|
| a | c | e | g | accumulation | based on ashfree dry weights |
| b | d | f | h | elimination | |
| i | k | m | o | accumulation | based on body burden |
| j | l | n | p | elimination | |

x = series 1
+ = series 2
o = series 3

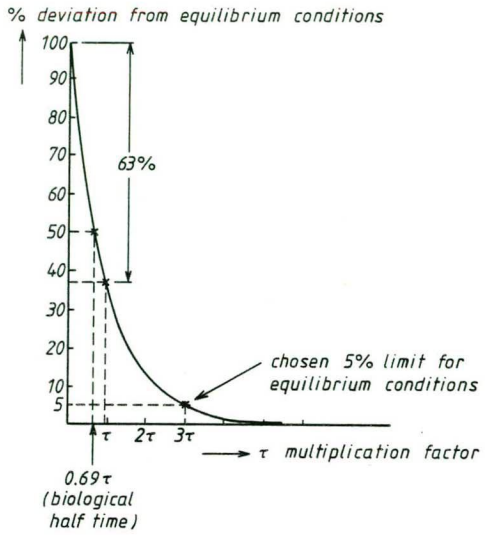



Fig. 10. Relationship between percentage distance to equilibrium conditions (of concentrations or body burden) and time expressed as multiplication factors of τ (time needed for a 63% deviation from initial process conditions).