THE OCCURRENCE OF SOME HEAVY METALS IN POPULATIONS OF THE FRESHWATER MUSSEL *ANODONTA ANATINA* (L.) FROM THE RIVER THAMES

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ABSTRACT

A survey was carried out to measure the existing levels of Zn, Ni, Pb, Cd, Cu and Hg in populations of the freshwater mussel Anodonta anatina *from three urban and four rural localities along the River Thames. The apparent influence of urban sewage outfalls was reflected by the relatively higher concentrations of Zn, Ni, Pb and Cd in mussels from the former areas, while those of Cu and Hg, metals which have more diffuse inputs, showed no such relationship. The maximal concentrations recorded for all metals exceeded those previously observed in* Anodonta *spp. and many marine lamellibranchs from the British Isles. Considerable differences were observed in the concentrations of all metals in mussels from the same locality, particularly among the immature individuals. Except for Ni, these were variously correlated with the dry body weight of mussels in the more highly contaminated populations. None of the metals was evenly distributed throughout the tissues of mussels and generally the mantle, ctenidia and kidneys were observed to contain the highest concentrations. An initial evaluation is made of the potential of the species as an indicator organism.*

INTRODUCTION

The ability of lamellibranch molluscs to concentrate heavy metals to levels far in excess of those in the hydrosphere is well documented (Brooks & Rumsby, 1965; Pringle *et al.*, 1968; Kopfler & Mayer, 1969; Bryan, 1973; Romeril, 1974; Schulz-Baldes, 1974; Watling & Watling, 1976 are among the principal authors) and, therefore, some emphasis has been given to their usefulness as indicators of a

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potentially harmful build-up of these elements in the environment (Schuster & Pringle, 1969; Huggett *et al.*, 1973; Majori & Petronio, 1973; Schulz-Baldes, 1973; Darracott & Watling, 1975). Some authors have suggested that as the metals are not normally evenly distributed throughout the tissues of bivalves, some organs may be of particular value as indicators of pollution (Schelske *et al.*, 1966; Bryan, 1973; Alexander & Young, 1976). The research carried out on this topic to date has been largely confined to marine and estuarine lamellibranchs, although studies by Baker (1922) and Nelson (1961) of several species of North American freshwater bivalves are notable exceptions. This was a principal factor in the choice of the freshwater mussel *Anodonta anatina* (L.) as the subject of the present study, the aim of which was to measure the existing levels of selected heavy metals in populations of this animal from the River Thames and to make a preliminary assessment of its potential as an indicator organism.

Anodonta anatina, a member of the Unionidae, is widely distributed over much of Britain in a variety of freshwater habitats (Boycott, 1936). It is a slow-moving, filter-feeding animal which occurs in abundance in the River Thames above Teddington lock. Negus (1966) studied the growth and production of a population in the river near Reading and confirmed the opinion of Crowley (1957) that the regularly spaced dark lines on shells, easily distinguishable from the much fainter, irregularly interposed, disturbance rings, were due to annual interruptions in growth. She observed that mussels grew to a maximal shell length of 95·5 mm and lived up to 10 years, although corresponding figures of 105·5 mm and 11 years were obtained during the present study.

Limited published data are available concerning the levels of heavy metals in natural populations of *Anodonta* spp. Segar *et al.* (1971) quote figures for the levels of nickel, lead and copper in the soft tissues and shells of a small number of *Anodonta* of unspecified species collected from a lake in Anglesey, North Wales. Leatherland & Burton (1974) give the levels of zinc, cadmium and mercury in the soft tissues of a very small number of *Anodonta cygnaea* collected from a single location in each of the rivers Thames and Test.

SAMPLING AND ANALYSIS

Description of sites

Anodonta anatina was collected from the River Thames at the seven localities shown in Fig. 1 and Table 1 between 18 December 1974 and 8 May 1975.

Sampling

At each locality, mussels within the range 1 to 11 years were collected using SCUBA from within areas of the river bed not exceeding 400 m^2 and from depths between 0·5 to 4·0 m. Subsequently they were allowed to purge themselves by maintaining them unfed for two days in polythene lined tanks in filtered water having a low trace metal content.

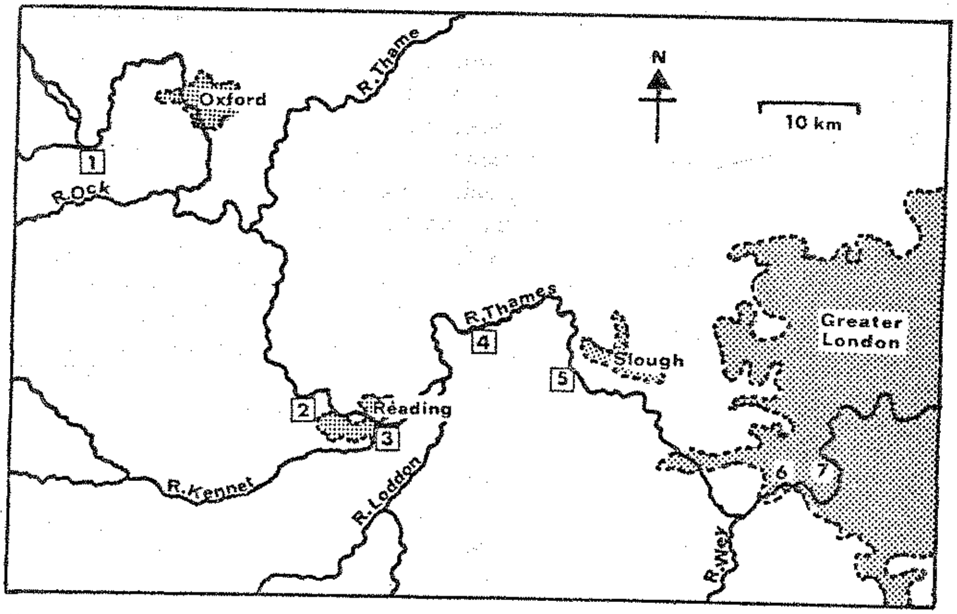

Fig. 1. Sampling localities. 1, Appleton; 2, Pangbourne; 3, Reading; 4, Hurley; 5, Bray; 6, Sunbury; 7, Teddington. Stippling represents heavily urbanised areas.

TABLE 1

LOCATION AND FEATURES OF SAMPLING SITES

Location	*Description of surrounding area*	*Total sewage discharge within 5 km upstream of sampling site 1/day*[a]
Appleton, Oxfordshire	Rural	$327{\cdot}3 \times 10^3$
Pangbourne, Berkshire	Rural	$181{\cdot}8 \times 10^3$
Reading, Berkshire	Urban	$477{\cdot}3 \times 10^5$
Hurley, Berkshire	Rural	$218{\cdot}2 \times 10^3$
Bray, Berkshire	Rural	None
Lower Sunbury, Middlesex	Urban	$854{\cdot}6 \times 10^5$
Teddington, Middlesex	Urban	$454{\cdot}6 \times 10^5$

[a] Figures supplied by the Thames Water Authority.

Analyses

For analysis of the soft tissues of mussels 14 to 16 individuals of known size were removed from their shells and dried to constant weight at 85 °C in acid-cleaned porcelain dishes. To solubilise the tissues 10 ml concentrated nitric acid (Analar grade) was added and the dishes covered and left for at least 24 h to allow for the dissolution of the refractory muscular tissues. The samples were then reduced to approximately 1 ml in volume by heating on a water bath, the residue filtered with washing and made up to 25 ml in a volumetric flask using de-ionised water. Five blank solutions were made up simultaneously with the samples to determine background corrections in the reagents.

Analyses for zinc, nickel, lead, cadmium and copper were performed with conventional flame atomisation using a Techtron AA6 atomic absorption spectrometer fitted with a deuterium background corrector. Analysis for mercury was carried out on the same instrument, but using a flameless 'cold vapour' technique (Parker, 1972) which has a greater sensitivity for this element than flame methods. The instrument was calibrated using the method of standard additions, thus avoiding errors due to matrix effects.

Similar analyses were performed separately on the mantle, ctenidia, digestive gland (including stomach), kidneys (including small parts of the pericardial cavity), gonad, foot and adductor muscles of *Anodonta* over 6 years old from Reading. Each sample consisted of the pooled tissues of six mussels.

RESULTS

Relationship between body weight and age of mussels

At all localities the relationship between dry body weight and age for the total population of *Anodonta*, apart from gravid females, is linear when plotted on a semi-logarithmic scale, although variations exist in the slopes of the calculated regression lines (Fig. 2). Attempts to correlate the latter with differences in the concentrations of metal(s) in each of the populations of mussels were unsuccessful. Gravid females, easily distinguished by the presence of large numbers of glochidia in the gill chambers, were heavier for a given age than other mussels, a feature also noted by Negus (1966). In view of this, and because the glochidia could not be satisfactorily removed from the gills, the small number of gravid females in each sample were not included in the analyses.

Concentrations of heavy metals in the soft tissues of mussels in relation to their body weight

Examination of the data showed that considerable differences existed in the concentration on a weight specific basis ($\mu g\, g^{-1}$ dry weight) of heavy metals in the soft tissues of mussels from the same locality. Similar differences have been observed in other lamellibranch species (Fitzgerald & Skaven, 1963; Kopfler & Mayer, 1969; Bryan, 1973; Huggett *et al.*, 1973) and it has been suggested that these are related to variations in the body weight of individuals (Schulz-Baldes, 1973; Boyden, 1974; Watling & Watling, 1976). In order to determine the validity of this with respect to *Anodonta*, the data for all elements from each locality were plotted as in Fig. 3(a)–(f), which illustrate representative examples and, for each, correlation coefficients for the logarithmic relationship between the concentration of metal and dry body weight were calculated (Table 2).

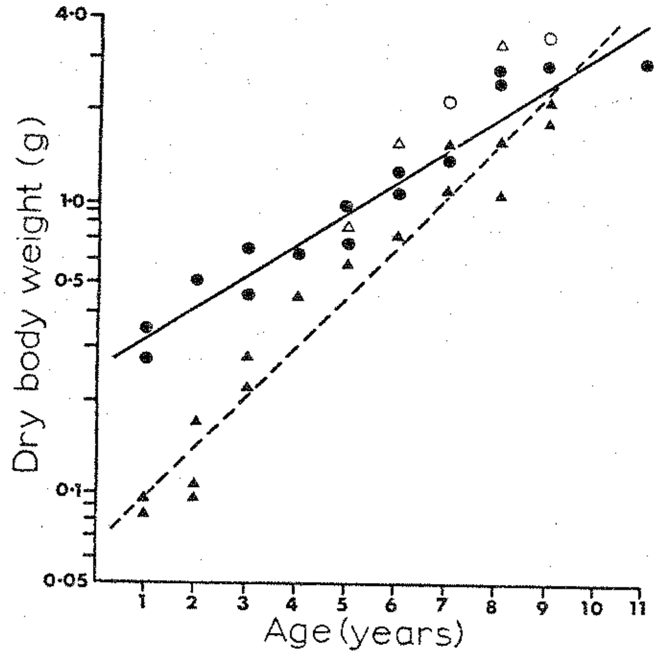

Fig. 2. Relationship between dry body weight and age in *Anodonta anatina*. ●—● Reading; ▲– –▲ Hurley. Open symbols represent gravid females.

The results showed that, at those localities where the concentration of any metal in mussels was comparatively low, no correlation between this and their body weight was apparent (Fig. 3 and Table 2). However, with the exception of nickel, at localities where the contamination of mussels was higher, relationships between the concentration of metal and body weight were observed which varied according to the element concerned (Table 2). At Reading, Lower Sunbury and Teddington the concentration of zinc increased sharply from relatively low levels in 1 year old mussels to reach a peak in 4 to 5 year old individuals, before declining again more gradually (Fig. 3(a)). Also in areas of higher contamination the concentrations of lead (Fig. 3(c)) and cadmium (Fig. 3(d)) in mussels increased with body weight, particularly in those up to 3 to 4 years old, the reverse being true for copper (Fig. 3(e)). Correlations similar to those observed for copper were evident for mercury in mussels from Appleton and Reading (Fig. 3(f)), but not in those from Hurley and Pangbourne, despite the fact that the mean concentrations were comparable at all four localities (Table 3). For nickel, no correlation was apparent in any sample.

In addition, where appropriate, logarithmic regression coefficients were determined for the above relationship to facilitate comparisons with the results of

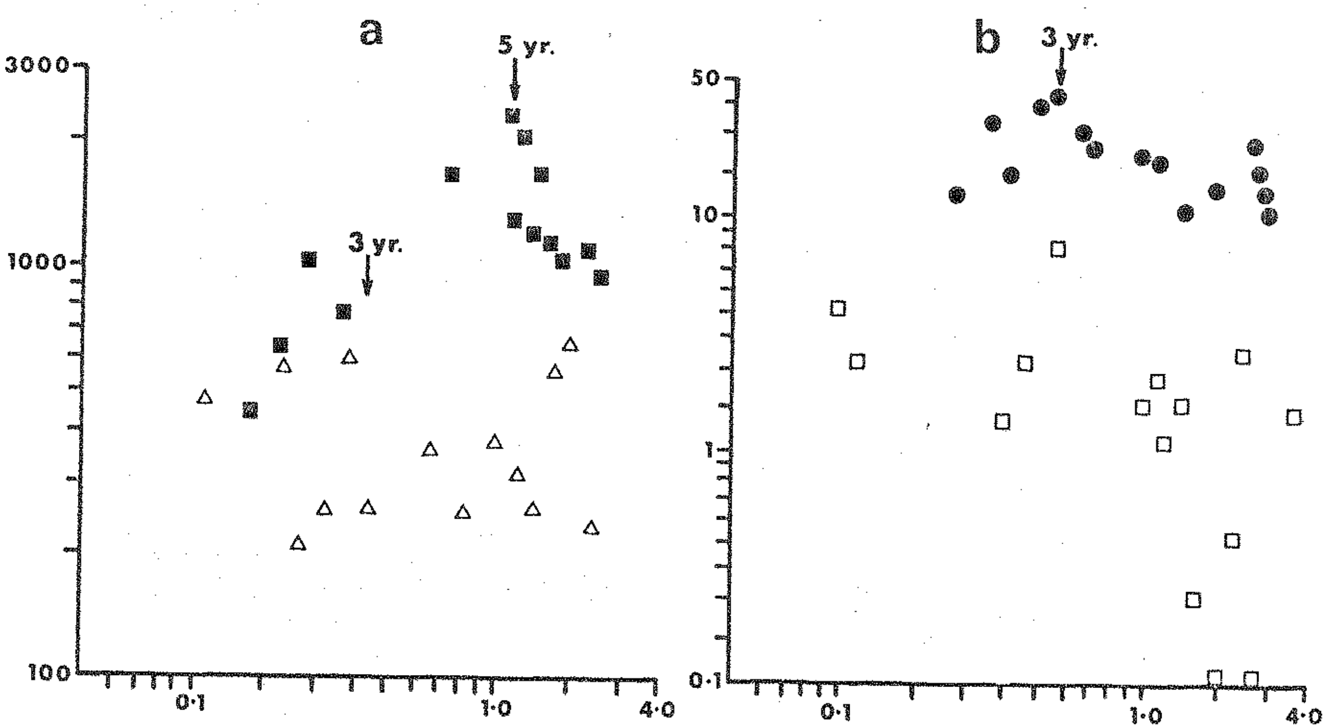

Fig. 3. Relationship between metal concentration and dry body weight in *Anodonta anatina*. (a) zinc; (b) nickel; (c) lead; (d) cadmium; (e) copper; (f) mercury. (▼) Appleton; (□) Pangbourne; (●) Reading; (·) Hurley; (△) Bray; (■) Sunbury; (▲) Teddington. Arrow shows average weight at age indicated. Ordinate, concentration of metal ($\mu g\ g^{-1}$); Abscissa, dry body weight (g).

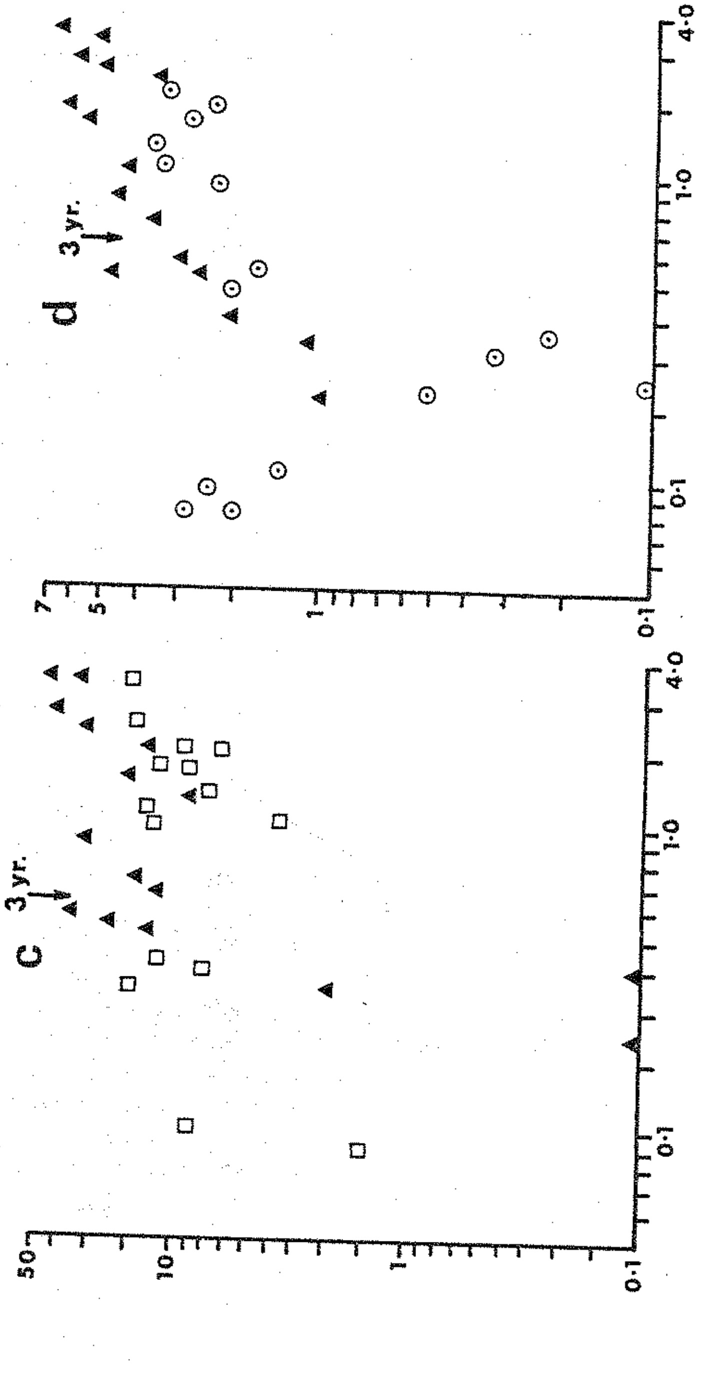

Fig. 3—*contd.*

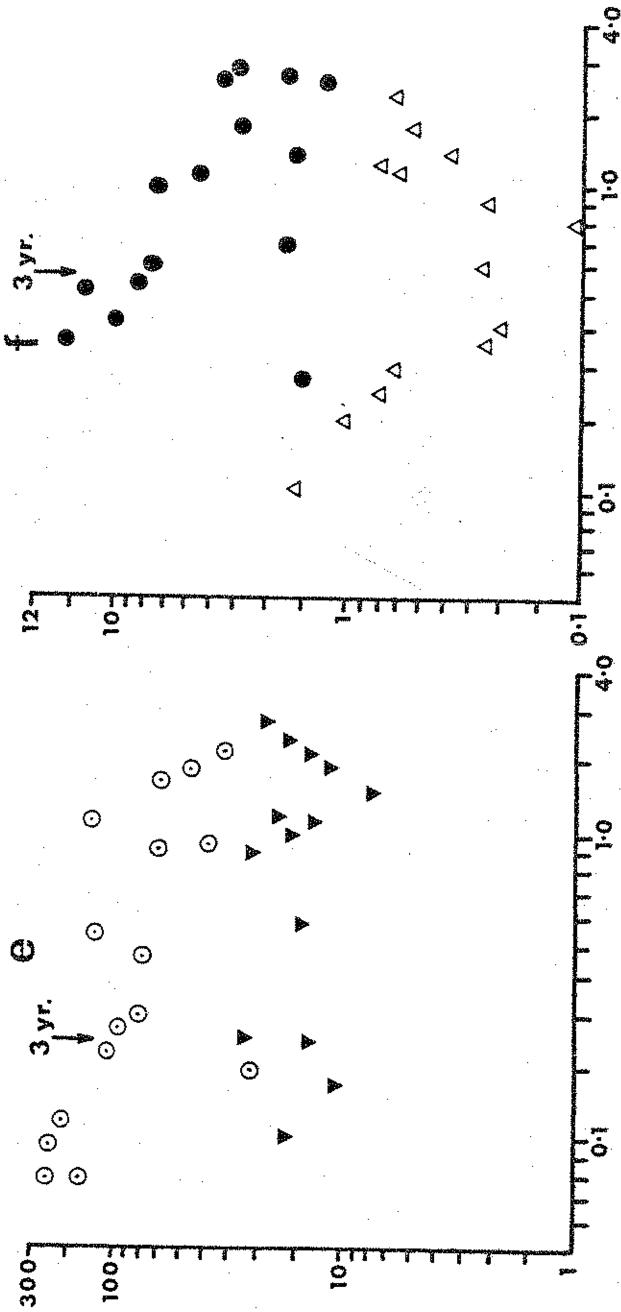

Fig. 3—*contd.*

TABLE 2

RANGE OF METAL CONCENTRATIONS IN THE SOFT TISSUES OF 14 TO 16 *ANODONTA*, THE SIGNIFICANCE (AT 5% LEVEL) OF LOGARITHMIC CORRELATION COEFFICIENTS RELATING THESE TO DRY BODY WEIGHT AND LOGARITHMIC REGRESSION COEFFICIENTS FOR THESE RELATIONSHIPS

Location	*Metals* ($\mu g\ g^{-1}$ *dry weight*)					
	Zn	*Ni*	*Pb*	*Cd*	*Cu*	*Hg*
Appleton	219·8–533·1 NS	0·5–7·3 NS	1·5–21·7 NS	0·1–6·1 NS	8·2–36·8 NS	3·1–11·8 S (−0·48)
Pangbourne	152·2–929·4 NS	0·1–7·6 NS	2·1–22·1 NS	0·1–7·1 S (0·52)	38·9–111·1 NS	0·2–9·7 NS
Reading	523·2–3496·5 NS	11·4–45·4 NS	12·6–79·4 S (0·42)	2·2–9·7 S (0·74)	40·7–137·4 S (−0·7)	1·4–11·2 S (−0·69)
Hurley	303·6–875·0 NS	0·1–12·0 NS	0·1–28·3 NS	0·1–3·4 NS	30·8–250·0 S (−0·86)	0·7–18·1 NS
Bray	200·8–686·3 NS	0·1–8·5 NS	0·1–23·1 NS	0·1–1·2 NS	34·7–222·2 S (−0·93)	0·1–2·1 NS
Lower Sunbury	436·4–2266·6 NS	9·6–20·2 NS	18·3–134·2 S (0·97)	0·1–21·1 S (0·96)	12·3–144·0 NS	0·5–1·4 NS
Teddington	708·9–3225·8 NS	0·1–45·9 NS	0·1–44·4 S (0·64)	1·0–6·6 S (0·67)	26·1–106·7 NS	0·4–1·0 NS

Boyden (1974). The coefficients obtained varied considerably according to the metal and the sampling locality (Table 2).

Concentrations of heavy metals in the soft tissues of mussels as related to the site of collection

In a number of previous studies it has been assumed that the variability described above was normally distributed around a population mean, of which the sample mean was a close approximation. However, the sampling employed in the present study was based on the visual location of mussels and the younger, smaller individuals were almost certainly under-represented in samples. For this reason (and because in the more highly contaminated mussels there are, except for zinc and nickel, greater age-dependent variabilities in metal concentrations in those up to 3 to 4 years old than in older individuals) it was decided to exclude mussels 3 years old or less from the calculation of a sample mean for all elements.

A summary of the analytical results obtained is given in Table 3. It can be seen that the mean levels of zinc, nickel and lead in mussels collected from the urban localities of Reading, Lower Sunbury and Teddington were higher than those in mussels from the four rural sites. A hierarchical analysis of variance applied to the data, indicated that these differences were significant at the 5%

TABLE 3

MEAN CONCENTRATIONS OF METALS IN SOFT TISSUES OF *ANODONTA*

Location	*Dry weight of soft tissues (g) Mean ± SD*	*Number of mussels sampled*	*Metal concentration (μg g⁻¹ dry weight)*					
			Zn Mean ± SD	*Ni Mean ± SD*	*Pb Mean ± SD*	*Cd Mean ± SD*	*Cu Mean ± SD*	*Hg Mean ± SD*
Appleton	1·5 ± 0·8	10	403·2 ± 154·4	4·2 ± 2·5	9·8 ± 4·5	3·2 ± 2·1	21·4 ± 8·4	7·0 ± 2·9
Pangbourne	1·3 ± 0·7	10	536·4 ± 259·3	1·3 ± 1·1	13·6 ± 6·4	3·9 ± 2·1	73·5 ± 25·1	5·4 ± 3·1
Reading	1·5 ± 1·0	10	1738·8 ± 872·4	24·9 ± 9·7	42·5 ± 19·9	5·9 ± 2·3	103·3 ± 33·6	5·7 ± 2·1
Hurley	1·4 ± 0·6	10	498·2 ± 180·0	4·5 ± 3·9	11·7 ± 10·3	2·0 ± 1·2	99·3 ± 69·6	8·2 ± 5·9
Bray	1·2 ± 0·5	10	426·1 ± 160·3	5·0 ± 3·9	13·4 ± 6·7	0·4 ± 0·5	91·6 ± 58·8	0·4 ± 0·3
Lower Sunbury	1·3 ± 0·7	10	1388·1 ± 512·1	16·3 ± 3·4	25·6 ± 4·7	3·9 ± 0·6	65·0 ± 48·0	0·9 ± 0·8
Teddington	1·5 ± 0·9	10	1817·7 ± 885·6	12·8 ± 6·9	22·7 ± 13·1	4·6 ± 1·4	65·7 ± 27·1	0·7 ± 0·3

level. The mean levels of cadmium also tended to be higher in mussels from urban localities, but the differences between the two groups were not significant. Indeed, the mean concentrations of this metal in the samples from Sunbury and Pangbourne were identical.

Such differences were not apparent with regard to the levels of copper and mercury in mussels. Although the maximum and minimum mean concentrations of copper, 103·3 ± 33·6 and 21·4 ± 8·4 μg g^{-1}, were observed in *Anodonta* from Reading and Appleton respectively, the levels in those from the remaining rural localities were higher than in mussels from Lower Sunbury or Teddington. The maximum and minimum mean concentrations of mercury, 8·2 ± 5·9 and 0·4 ± 0·3 μg g^{-1}, were present in mussels from Hurley and Bray respectively, with the mean levels in those from the other rural areas exceeding 5 μg g^{-1}. In contrast, the mean concentration of this element in mussels exceeded 1 μg g^{-1} at only one urban locality, Reading.

The distribution of metals in the tissues of mussels

The results of these analyses are given in Table 4.

Zinc: The highest concentrations of this element occurred in the mantle, ctenidia and kidneys, which together accounted for over 88% of the total zinc content of mussels. The digestive gland and gonad contained substantially lower levels and only minor quantities were present in the foot and adductor muscles.

Nickel: By far the largest concentration of this metal, 138·8 μg g^{-1}, was found in the kidneys; however, due to the relatively small size of these organs, this represented only 14·6% of the total nickel in the mussels. Most of the remainder occurred in the mantle and ctenidia. As with zinc, the foot and adductor muscles contained the lowest concentrations.

Lead: The highest levels of lead were present in the digestive gland and kidneys.

TABLE 4

CONCENTRATIONS OF METALS IN TISSUES OF *ANODONTA* (μg g^{-1} DRY WEIGHT) AND QUANTITY OF METAL AS A PERCENTAGE OF THE TOTAL IN SOFT TISSUES (in parentheses)

Metal	*Mantle*	*Ctenidia*	*Digestive gland*	*Kidneys*	*Gonad*	*Foot*	*Adductor muscles*
Zn	1270·4 (26·1)	1378·2 (50·8)	415·3 (0·8)	1005·0 (11·2)	508·4 (1·5)	58·9 (4·5)	131·4 (5·1)
Ni	35·0 (19·5)	37·8 (37·7)	18·1 (3·8)	138·8 (14·6)	24·3 (1·5)	9·4 (16·9)	6·6 (6·0)
Pb	42·5 (14·7)	47·9 (29·8)	100·0 (6·1)	98·7 (17·2)	46·1 (4·1)	25·2 (7·4)	21·3 (20·7)
Cd	1·2 (9·3)	1·9 (27·0)	3·4 (12·2)	0·5 (34·0)	4·0 (0·5)	2·2 (0·9)	0·1 (16·1)
Cu	81·2 (23·8)	89·9 (47·4)	38·1 (2·6)	81·2 (9·6)	30·4 (3·1)	12·7 (6·9)	19·2 (6·6)
Hg	6·2 (15·4)	6·0 (28·5)	5·0 (10·1)	15·0 (21·9)	8·0 (8·1)	5·6 (8·4)	5·8 (7·6)

Those in the mantle, ctenidia and gonad were similar and approximately half those in the aforementioned organs, but because of their comparatively larger size, combined they contained nearly 50% of the lead content of mussels.

Cadmium: A large proportion of the total amount of cadmium lay in the ctenidia, digestive gland and gonad with $<1\%$ occurring in the kidneys. It is also noteworthy that while the level of cadmium in the muscular foot was $2{\cdot}2\,\mu g\,g^{-1}$, that in the adductor muscles was only $0{\cdot}1\,\mu g\,g^{-1}$.

Copper: Proportionately, this metal had a similar distribution to that of zinc.

Mercury: Apart from appreciably higher concentrations in the kidneys, the levels of mercury throughout the other tissues were remarkably similar and were unusual in that the adductor muscles and foot contained over 7% and 8% respectively of the total mercury content of mussels.

DISCUSSION

The daily flow of sewage effluent, which is known to be rich in all the heavy metals involved in the present study (Berrow & Webber, 1972), is at least 13 times greater in the vicinity of the urban sampling sites than in that of rural areas (Table 1). Additional sources of these metals, which are provided by industrial effluents not discharged through the public sewers, and of lead from motor vehicle exhaust emissions, also occur primarily in the former areas. It is, therefore, interesting to note that these differences are reflected in the presence of elevated levels of zinc, nickel, lead and, to a lesser extent, cadmium in *Anodonta anatina* from urban localities (Table 3). However, compounds of copper and mercury have extensive applications as agricultural pesticides and the entry of these, or their derivatives, into the river as run-off from the land is probably responsible for the very high concentrations of these elements in mussels from a number of rural areas (Table 3). Several authors, including Ackefors *et al.* (1970) and Holden (1973) have emphasised the importance of metal-containing pesticides as a source of contamination of aquatic organisms.

The maximum observed levels of all elements were higher than those previously recorded in species of *Anodonta* in the British Isles. In particular, the concentrations of nickel, lead and copper were respectively 71, 35 and 34 times greater than those in *Anodonta* (species unspecified) collected from a lake in Anglesey, North Wales (Segar *et al.*, 1971). However, no indication was given by the authors of the degree of pollution in the lake. The greatest concentrations of zinc and mercury observed in *Anodonta cygnaea* from the River Thames by Leatherland & Burton (1974) were comparable to the lowest recorded in the present study, but the highest levels of cadmium were similar in both investigations. Fish are known to be among the most prodigious concentrators of mercury (see Holden (1973) for review); therefore, the high levels of this metal observed in mussels from Reading, Appleton, Pangbourne and Hurley, the mean concentrations of which ranged from 5·4–8·2 μg g^{-1}, are of particular interest. These figures considerably exceed the estimated average of approximately 1 μg g^{-1} mercury for shellfish in England and Wales (MAFF, 1971) and compare with those recorded in freshwater fish from rivers highly contaminated by this metal (MAFF, 1973).

With the exception of nickel, the considerable variations in the concentrations of all metals in mussels from the same locality were apparently related to dry body weight in some or all of the samples comprised of more highly contaminated individuals (Table 2, Fig. 3(a)–(f)). In these, the concentrations of copper and mercury decreased and those of lead and cadmium increased with increasing body weight (zinc was exceptional in that the concentration first increased, then abruptly decreased with a rise in body weight). In mussels with low levels of contamination the concentrations of metals were not correlated with body weight but fluctuated, apparently at random, between the extremes. These results suggest that the body levels of copper and, in some cases, mercury are moderately well regulated by *Anodonta* under all the conditions of pollution observed. This may also apply to lead and cadmium at the lowest levels of contamination, but, when this increases, excretion appears to be superseded by accumulation and/or storage.

For all elements the regression coefficients for the logarithmic relationship between the concentration of metal in the tissues and the dry body weight of mussels varied considerably with the locality and in many instances could not be calculated because of the absence of any correlation between these parameters (Table 2). Therefore, there is no evidence from the present study to support the suggestion made by Boyden (1974) that for a particular element and species of shellfish such regression coefficients may remain relatively constant irrespective of such factors as location.

There is evidence, however, that with the exception of zinc, weight-dependent variabilities in metal concentrations become reduced after the mussels are 3 to 4 years old. Negus (1966) observed that *Anodonta anatina* in the River Thames at Reading become mature when 3 years old: the possibility exists, therefore, that the physiological changes taking place in the mussels at this time subsequently influence their ability to regulate the uptake of metals. However, this does not explain why the concentrations of zinc in highly contaminated mussels increases sharply in individuals up to 5 years old and then decreases abruptly and almost as rapidly.

The metals were not evenly distributed throughout the tissues of mussels. Each element had a somewhat different distribution from the others and in this respect those of zinc and cadmium, which were almost the inverse of one another, are of special interest. This is a feature noted by Brooks & Rumsby (1965) in their study of marine bivalves in New Zealand. These two elements are chemically similar and it may be that within the tissues they are physiologically antagonistic as a result of competition for protein-binding sites. This is known to occur in human tissues (Underwood, 1974).

Relatively high concentrations of all metals, but of zinc and copper in particular, were recorded in the mantle and ctenidia of mussels. As these organs together constitute on average >40 % of the dry body weight of individuals, they seemingly contain a substantial proportion of the total metal content of mussels. In fact the data in Table 4 show that the figure ranges from 36·3 % for cadmium to 76·9 % for zinc. High levels of a number of heavy metals in the ctenidia of lamellibranchs have been recorded by numerous authors, among them Brooks & Rumsby (1965), Pringle *et al.* (1968) and Bryan (1973). However, care must be taken in interpreting these results. According to Korringa (1952) positive polyvalent ions such as Zn^{++}, Cu^{++} and Hg^{++} become concentrated on to mucus sheets, such as those covering the ctenidia and, to a lesser extent, the mantle of *Anodonta*, as a result of ion-exchange mechanisms. Since mucus is an extracellular product, these ions are not assimilated within the tissues, but rather adsorbed to a surface layer undergoing constant renewal.

In *Chlamys* and *Pecten* the kidneys act both as organs of excretion and storage (Bryan, 1973). The high concentration of all metals, except cadmium, in the kidneys of *Anodonta anatina* is evidence that the same may be true for this species. However, unlike the former two genera, the metal contained in the kidneys of *Anodonta* represents only a small fraction of the total metal content of the mussel. The digestive gland contained substantial concentrations of lead and cadmium, but little else. High levels of lead have been recorded from this organ in the marine lamellibranchs *Crassostrea virginica* (Pringle *et al.*, 1968), *Chlamys* and *Pecten* (Bryan, 1973). The gonad also contained substantial levels of cadmium and to a lesser extent lead. Both have mutagenic properties and are among the most toxic heavy metals; therefore, the possibility that their presence in this organ has an adverse effect on the fecundity of mussels cannot be overlooked.

The low levels of most metals found in the foot and adductor muscles of *Anodonta* was not unexpected as they have no absorptive or secretory function and indeed this is a feature of the same tissues in other lamellibranch species (Segar *et al.*, 1971; Bryan, 1973). Nevertheless, in *Anodonta* mercury proved an exception as it occurs at moderately high levels in both tissues. Similarly, the muscular tissues of freshwater fish have been found to contain high concentrations of this element (see Holden, 1973, for review).

To summarise, *Anodonta anatina* appears to have some value as an indicator of heavy metal pollution. It can accumulate substantial quantities of all the metals studied here and there is evidence to suggest that the extent to which it does so is related to the levels of these in the environment. Precise knowledge of the concentrations of available metals in the river water and bottom sediments, which are needed to confirm this, is extremely difficult to obtain since they change constantly as a result of the erratic and transitory fluctuations in environmental conditions that characterise lotic habitats. Although the variable nature of the relationship between dry body weight and metal concentration represents an apparently serious disadvantage, its effects can be minimised by the exclusion of immature mussels from any analysis, since it is in these that such variability is at its greatest. Finally, a number of individual tissues and organs contain high concentrations of most metals, but there is no advantage to their selection as indicators of metal pollution in preference to whole mussels, although the exclusion of the refractory muscular tissues, which contain little metal, would reduce the time taken for analysis.

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