

Mercury Levels in Biota and Sediments of Princess Royal Harbour, Albany, Western Australia: Interpretation and Management Implications

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ABSTRACT

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A minor Hg discharge ($14.2 \text{ kgHg yr}^{-1}$) over 30yr to Princess Royal Harbour resulted in Hg levels in the edible flesh of fish to range 0.01 to 7.6 mg/kg^{-1} wet wt with high values occurring in carnivorous species. Hg levels in cockles (all soft tissues) ranged 2.2 to 50 mg/kg^{-1} wet wt. These values are moderately high and exceed the Australian health standard of 0.5 mgHgkg^{-1} wet wt for foodstuffs. (The contaminated part of the harbour has been closed to fishing). Levels in sediments are low by world-wide comparison, with a maximum value of 2.2 mg/kg^{-1} dry wt found in fine detritus-rich surface sediment in a seagrass meadow at a considerable distance from the outfalls. Those in quartz-rich (sand) sediments around the outfalls are very low, ranging 0.04 – 0.11 mg/kg^{-1} dry wt, indicating little affinity for Hg.

Whilst flushing is good (14 days) and water velocities reach 0.5 ms^{-1} , lack of turbulence allows buildup of Hg-contaminated detritus in seagrass meadows, which act as a natural particulate trap in addition to adsorbing Hg. Hg accumulation up the foodchain is probably due to contaminated seagrass/detritus acting as a fish nursery and food source for both fish and benthic organisms which they predicate.

Results are discussed in terms of remedial action and natural value of the contaminated area, suitability of health standards and discharge management. Because export of contaminated particulates and detritus is low, the problem may remain for some time. Hg discharge to seagrass meadows and organic-rich sediments should not occur, regardless of flushing rates and water velocities. Given the high Hg levels in larger marine species around Australia, Hg discharge to coastal waters should be generally avoided.

ADDITIONAL INDEX WORDS: *Receiving water regime, seagrass, inorganic sediments, detritus, Hg standard, Hg discharge, fertilizer, superphosphate, coastal water.*

INTRODUCTION

In 1983, the edible portion of fish (flesh only) and shellfish (all soft tissues) from Princess Royal Harbour, Albany, Western Australia (Figure 1) were found to contain Hg ranging 0.01 to 7.6 and 2.2 to 50 mg Hgkg^{-1} wet weight (Table 1) (JACKSON *et al.*, 1986) resulting in partial closure of the harbour to fishing. These levels are moderately high when compared with those in biota from other polluted areas around the world (PROSI, 1979): Highest values in fish were found in carnivorous species, indicating a diet Hg-accumulation relationship. The Australian National Health and Medical Research Council standard for Hg in human foodstuffs is 0.5 mg Hgkg^{-1} wet weight (NH&MRC, 1983).

This problem was considered unusual as pre-

liminary data indicated low Hg levels in harbour sediments compared with levels found in polluted sediments elsewhere (FORSTNER, 1979). In addition, JACKSON *et al.* (1986) showed that the source was minor whilst MILLS and BRADY (1985) indicated that the harbour was flushed well.

An explanation to the problem was sought in terms of the history of the source, and physical and biological characteristics of the receiving environment. This paper reports major factors contributing to accumulation of Hg in the system, in an attempt to explain the buildup of Hg in edible biota. In addition, it discusses remedial measures and management strategies.

STUDY AREA

Princess Royal Harbour is an almost landlocked elliptical shaped embayment with a

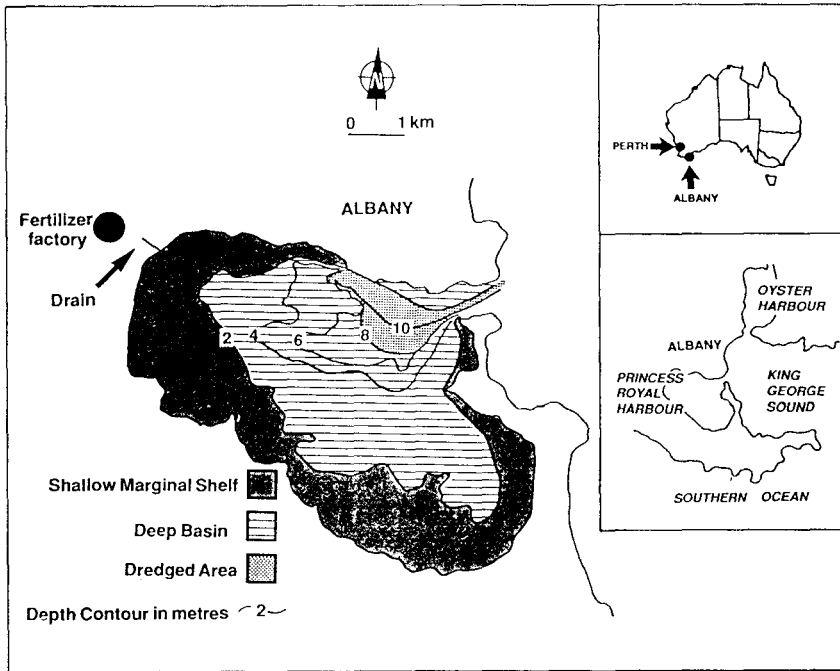


Figure 1. Location map showing physical characteristics of Princess Royal Harbour.

Table 1. Levels of Hg (mg kg^{-1} wet wt) in edible tissues of a variety of fish and one species of cockle (all soft tissue) in the western end of Princess Royal Harbour (Jackson et al., 1986). Note higher values in carnivorous species.

Species	X	Range
Aust. herring (<i>Arripis georgianus</i>) ^{pc}	0.70*	0.60-7.60
Cobbler (<i>Cnidogobius macrocephalus</i>) ^{bc}	0.83*	0.22-2.00
Leatherjacket, 6 spined (<i>Meuschenia freycineti</i>) ^{bc,d}	0.76*	0.14-1.60
King George whiting (<i>Sillaginodes punctatus</i>) ^{bc}	0.50*	0.09-1.10
Sea mullet (<i>Mugil cephalus</i>) ^{bd}	0.06	0.01-0.17
Yelloweye mullet (<i>Adrichetta forsteri</i>) ^{bd}	0.33	0.05-0.70
Sea garfish (<i>Hyporhamphus melanochir</i>) ^{bd}	0.26	0.08-0.37
Flathead (<i>Platycephalus laevigatus</i>) ^{bc}	3.20*	1.30-7.20
Small toothed flounder (<i>Pseudorhombus jenynsii</i>) ^{bc}	1.30*	0.36-2.50
Yellowtail scad (<i>Trachurus maccullochi</i>) ^{pc}	5.80*	4.50-7.10
Blue weed whiting (<i>Haletta semifasciata</i>) ^{bc}	3.40*	3.4
Cockles (<i>Katylsia scalarina</i>)	7.20*	0.40-5.0

* = mean values on or above the health standard for Hg in edible food.

^b = benthic; ^p = pelagic; ^c = carnivorous; ^d = detritus.

narrow opening to King George Sound (Figure 1). It is eight km long, four km wide and $28.8 \times 10^6 \text{m}^2$ in area. It is characterised by a deep basin (<8 m) with a sandy marginal shelf,

partly covered by seagrass meadows and algae around the western and southern shores. An area on the northern shore has been dredged (10 m) to facilitate shipping. Exchange of harbour

water and water from King George Sound occurs (ATKINS *et al.*, 1980). On flood tide water passes through the narrow harbour entrance (with speeds up to 0.5 ms^{-1} at maximum tide range) and traverses the harbour as a narrow tidal jet (up to 3 km). On the ebb tide, water leaving the harbour is drawn from a wider angle about the entrance channel, but from a smaller radius. Wind induces large horizontal water circulation gyres and promotes horizontal mixing (MILLS and BRADY, 1985). Generally, the harbour is also vertically well-mixed (ATKINS *et al.*, 1980). Total replacement time approximates 14 days (D.A. MILLS, EPA, Perth, *pers. comm.*, 1989). Flushing on the most polluted shallow western margin is strongly dependent on wind velocity and water level. Effective flushing occurs during south-easterly or north-westerly winds. Incoming tides are responsible for buildup of effluent, and the stranding of detritus from seagrass meadows along the western beach and sandy mud flats (ATKINS *et al.*, 1980). This has a critical effect on the dispersion of organic-binding pollutants (TALBOT, 1983) as will be shown later. Storm-water runoff and discharge channels provide the only input of freshwater.

HISTORY OF EFFLUENT SOURCE

JACKSON *et al.* (1986) showed the source of Hg contamination to be a fertilizer (superphosphate) plant that was commissioned in 1955. Initially, it discharged effluent to the harbour via a drain (Figure 1). In 1968 a 1 km 15 cm diameter plastic pipe was installed to bypass the drain and discharge it directly to the sandy mud flats (Figure 2, site 1). In 1982, the pipe was extended another 600 m to the edge of the sand flats (Figure 2, site 2) to gain better dispersion as the effluent was found to contain Pb (TALBOT, 1983). Upon identification of the Hg problem in 1984, the pipe was disconnected and discharge of untreated effluent ceased. The pipe was removed from the harbour in 1986.

It is noted that the volume of effluent discharged to the harbour was only $5.63 \text{ m}^3 \text{ h}^{-1}$ with a loading of about $14.2 \text{ kg Hg yr}^{-1}$ (JACKSON *et al.*, 1986). Under most circumstances such loading would have little impact on receiving coastal waters, because of Hg mobility, dilution and dispersion.

EXPERIMENTAL

Sampling and Analysis

Surface sediment samples (top 2 cm, $n=38$) were taken in sandy areas adjacent to the effluent outfalls and contaminated drain, and also in organic rich sediments in seagrass meadows to determine relationships between sediment type and Hg dispersion. In addition, 19 cores of 14 cm depth were taken in the western end of the harbour to determine degree of Hg penetration into the sediment. Samples were taken at 2 cm intervals down each core. Sampling procedures followed those of TALBOT (1983) and TALBOT and CHEGWIDDEN (1982).

Five whole seagrass plants (*Posidonia australis*) were taken 150 m east of site 2 (Figure 2) to investigate distribution of Hg within the plant and its relationship to Hg levels in sediments in which they had grown.

Sediment preparation and organic content (loss on ignition:LOI) analyses were carried out using the method of TALBOT (1983). The analysis method for Hg was similar to that of KOPP and McKEE (1983), except that increased amounts of sample were used for inorganic samples because of low Hg levels. This method was chosen because it has been standardized by the USEPA for sediments and is relatively quick and simple.

Statistical Analysis

As one of the main aims of the project was to determine factors causing buildup of Hg in various types of sediment, data were analysed using regression analysis and 1-way ANOVA with STATPACK (HOUGHARD and MEAGHER, 1974). The word 'significant' is used to mean $P < 0.001$. The geometric mean (G) was used to summarize data as it is a better estimate of central tendency than the arithmetic mean for small sample numbers (TALBOT and SIMPSON, 1983).

RESULTS AND DISCUSSION

Harbour Sediment Surveys

Figure 2 shows that Hg levels in harbour sediments are low and patchy. Table 2 shows that

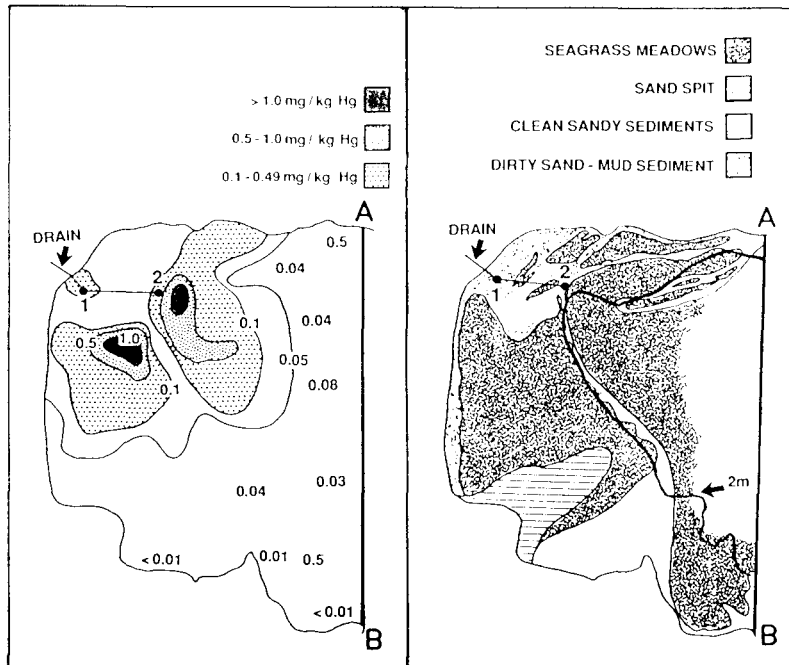


Figure 2. Location of contaminated drain, earlier effluent discharge point (site 1) and later discharge point (site 2). Mercury levels (dry wt) in sediments and seagrass dispersion are shown also to indicate their geographic distributions.

Table 2. Levels of Hg (mg kg^{-1}) in variously polluted marine sediments from around the world.

Relatively unpolluted sediment		
Source	Hg	Reference
Baffin Bay	0.02-0.08	Campbell and Loring, 1980
Bay of Naples	0.1-0.2	Baldi <i>et al.</i> , 1983
Gulf of Venice	0.13	Donazzolo <i>et al.</i> , 1981
Irish Sea	0.1-0.4	Rae and Aston, 1981
Plym Estuary	0.02-0.11	Millward and Herbert, 1981
Mildly polluted sediments		
Source	Hg	Reference
Firth of Clyde	1.86	Halcrow <i>et al.</i> , 1973
New Bedford Harb.	3.80	Summerhayes <i>et al.</i> , 1977
Santa Monica	6.10	Schafer and Bascom, 1976
Solent (S'hampton)	5.60	Leatherland and Burton, 1974
Heavily polluted sediments		
Source	Hg	Reference
Derwent Estuary	1130	Bloom and Ayling, 1977
Minamata Bay	2010	Kitamura, 1968

these Hg levels are similar to levels in relatively unpolluted marine sediments elsewhere (FORSTNER, 1979). Examination shows that highest levels of Hg in sediments tend to occur at sites where there are seagrass meadows (Figure 2). Levels of Hg in freshwater-affected sandy-mud flat sediments near the drain indicate some Hg accumulation whilst clean quartz-carbonate rich sediments between and south of the line joining the old and new outfalls (sites 1 and 2) contain little Hg. A simplified distribution plot of sediment types (Figure 2) shows that patches of seagrass grow on both clean sand and sandy-mud flats, and that there are localized areas containing elevated levels of Hg due to organic buildup. Seagrass cover on sandy areas is limited by water depth, however, as seagrass has to be immersed at low tide to avoid dehydration.

Hg in Core Sediments

Figure 3 shows four typical cores taken from four different types of sediment respectively from near the discharge points. Highest Hg val-

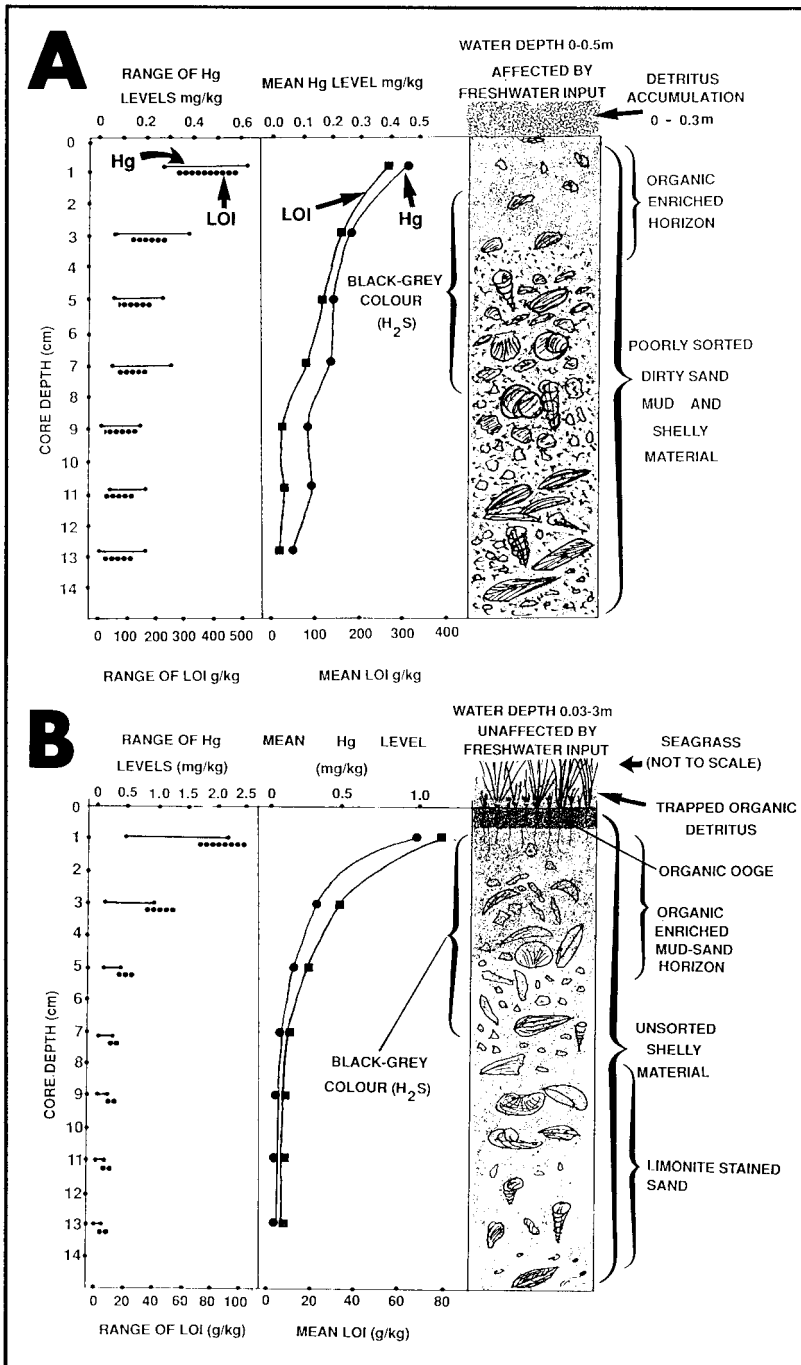


Figure 3. Physical and chemical characteristics of four different types of core taken from the following areas: (A) detritus laden beach, (B) seagrass meadows.

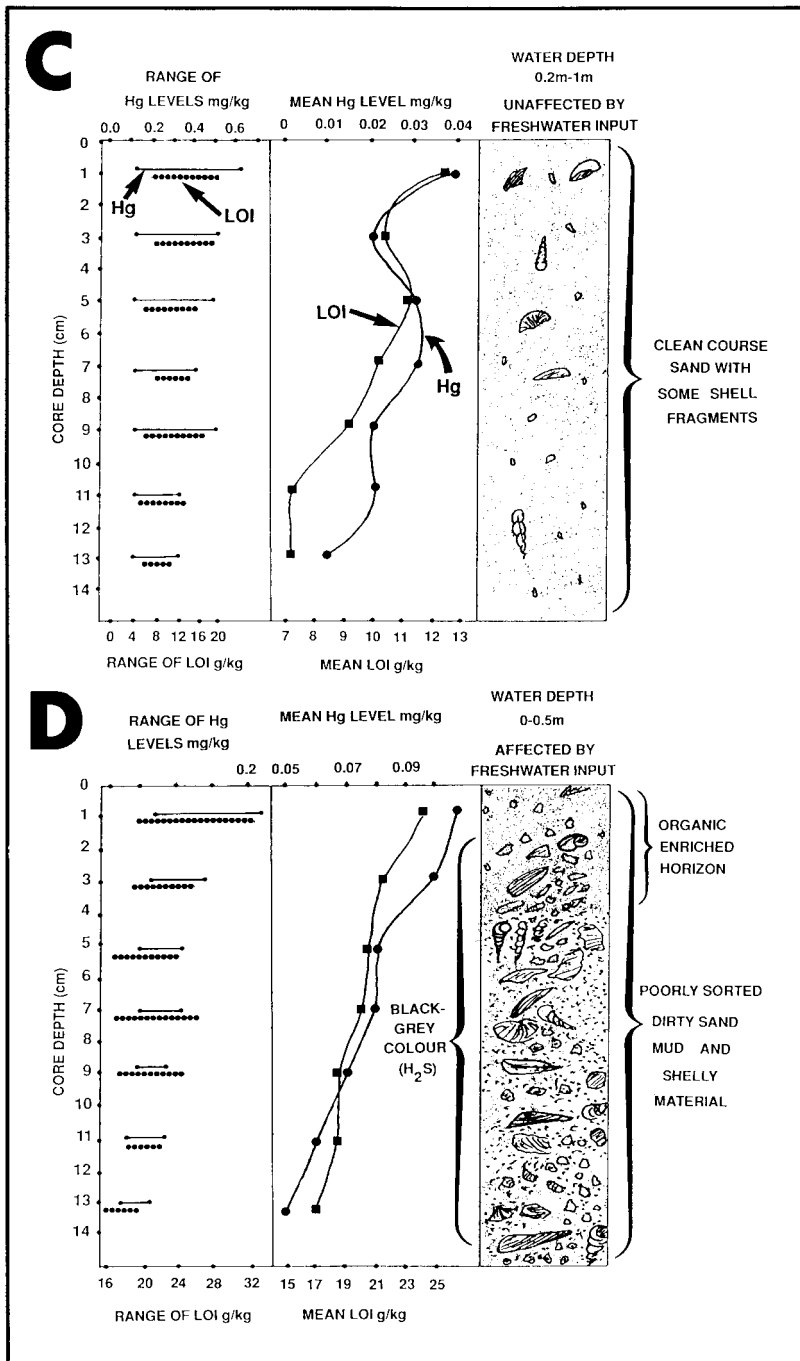


Figure 3 cont. (C) clean quartz-rich sand and (D) sandy-mud influenced by terrestrial runoff. Note the different scale sizes for data for the 4 cores, with A having the largest scale for LOI and B, the largest for Hg.

ues occurred in surface samples regardless of the area sampled. One-way ANOVA indicated Hg and organic (LOI) levels in the top 6 to 8 cm were significantly higher than lower down in cores taken from beach (A) and seagrass (B) areas (Hg; $F=27.5$, 13.8 ; LOI; $F=26.6$, 18.9 , respectively). Further, Hg and LOI levels correlate significantly for both cores ($r=0.82$ and 0.93) implying Hg accumulation is controlled by LOI content. This is supported by 1-way Anova of clean sand (C) and sandy-mud (D) cores which have relatively low levels of both LOI and Hg. Analysis showed no significant difference in Hg and LOI with depth (Hg, $F=6.39$, LOI, $F=7.16$; and Hg, $F=11.12$, LOI, $F=10.87$, respectively) even though Hg and LOI correlates significantly ($r=0.91$ and 0.60 respectively).

Levels of Hg increased slightly with depth between 4–8 cm in some cores where black-stained (H_2S) sediments occurred. Beneath approximately 10 cm, Hg and LOI levels decreased and limonite staining became more prevalent. It is concluded that apart from organic-binding Hg in surface sediments, low Eh resulting from organic buildup also causes Hg precipitation in sandy mud flats and detritus beach sediments.

Hg in Seagrass

Figure 4 shows relative dispersion of Hg within seagrass and sediment substrate. Levels are relatively uniform in seagrass except for low values at the plant base. MASERTI *et al.* (1988) showed Hg uptake occurred via rhizomes and concluded that seagrass could be used as a Hg-pollution monitoring species. STOKES and DREIER (1983) concluded similarly for filamentous algae. Given the adsorptive capacity of organic detritus for chalcophiles (sulphur seeking metals) such as Hg, it is probable that Hg-accumulation by seagrass can take place via surface leaf adsorption also.

The range of Hg levels in the shelly-mud substrate (Figure 4) may not appear to be significantly lower than that for seagrass. A better comparison would be between Hg levels in seagrass and clean silica-rich sediments. This is because the substrate of seagrass is usually enriched with Hg contaminated detritus. Further, as the detritus mineralises it produces reducing conditions which convert Hg to the

immobile HgS form. Where this is not the case, Hg values are < 0.1 mgkg⁻¹ dry wt. and usually around 0.05 mgkg⁻¹ dry wt.

Physical Factors Influencing the Problem

Whilst the harbour is well flushed, lack of wave energy and turbulence results in only minor resuspension and transport of organic detritus away from the western end of the harbour. Consequently, much Hg-rich detritus remains trapped in this area.

Sandy Mud Flats This area receives detritus-enriched stormwater from the contaminated drain. The organic content of sediments is relatively low, however, because water depth at low tide generally limits seagrass growth. Consequently, Hg accumulation in the sediment has been limited.

Clean Sand Adjacent to and South-West of the Newer Outfall The area is submerged, except under extreme low spring tides, but water depth is insufficient to sustain seagrass growth. Hence there is little potential for accumulation of polluted organics. In addition, it is sufficiently shallow for wave action and wind driven currents to resuspend, scour and transport organic particulates or detritus to adjacent deeper water (seagrass meadows) or to the beach where settlement or stranding occurs. Hence the lowest Hg levels occur in this area.

Beach Area Large quantities of Hg-contaminated seagrass and detritus accumulate intermittently on shore and rot. Accumulation occurs on incoming tides and onshore winds. Because the detritus accumulates randomly with respect to its source and the discharge points for Hg, its Hg levels are variable. Hence, Hg levels in beach sediment which it contaminates are also variable and bear only moderate relation to distance from the discharge areas.

Seagrass Meadows Seagrass grows extensively in two areas, immediately east of the 2 m contour (Figure 2), and in much shallower water south of the effluent pipe (Figure 2). The former is always submerged (1.5–3 m), shows serious signs of deterioration due to eutrophication (epiphytes) and is subject to little turbulence. Much of this meadow is smoth-

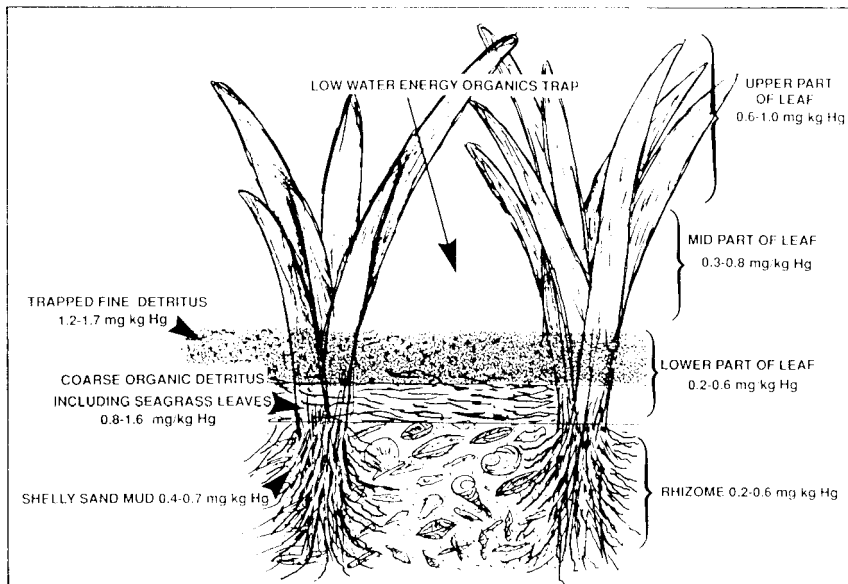


Figure 4. Relative dispersion of Hg (dry wt) in seagrass (*Posidonia australis*) and comparisons with values for the contaminated sediments in which it grows. Note the substrate contains fine grained Hg-contaminated detritus.

ered with Hg contaminated weed and detritus which shows no sign of or potential for transport. It forms an extensive habitat and nursery ground for juvenile fish and crustaceans apart from providing shelter and a food supply.

The latter meadow occurs in shallower water (0.5 m–2 m), is very dense, and the leaves bend and form a thick surface mat on outgoing tides. This meadow also behaves as a trap for contaminated organic particulates and detritus and serves as a nursery, shelter, and grazing (food source) area for biota.

Both meadows have served as a sink for Hg, and highest levels are found there, especially in the finer detritus. LINDBERG and HARRISS (1974) came to the same conclusion for detritus in mangroves, which contained between 3 to 30 times more Hg than the living plants.

Assessing Degree of Pollution

Comparisons can be made with other case histories, as Hg levels in biota and sediments are moderately high and low respectively (Tables 1 and 2). The most severe Hg pollution problem to occur was at Minimata Bay, Japan, where Hg was discharged in the bioaccumulating methyl

form. Whilst sediment values were very high (Table 2), they were not accompanied by proportionally high values in fish, shellfish, crustaceans or seaweed (KITAMARA, 1968; TAKEUCHI, 1972 and NRIAGU, 1979).

The Derwent Estuary is the most heavily polluted estuary in Australia (Table 2). Whilst levels of Hg in sediments were high, Hg levels in various species of shellfish ranged as low as 0.01–2 mg/kg wet weight (BLOOM, 1975) and below detection to 2 mg/kg wet weight for a range of fish (RATKOWSKY *et al.*, 1975). Both these case histories indicate moderately high Hg levels in biota in Princess Royal Harbour, given the nature and small magnitude of the discharge.

Hg Buildup in Biota

The major difference between Princess Royal Harbour and other Hg-polluted systems is that Hg-contaminated effluent waste was discharged onto seagrass meadows and algae. Unpublished work by the author indicates rapid accumulation of Hg by seagrass from this effluent. LINDBERG and HARRISS (1974) indicated that Hg-contaminated detritus represents

a natural mechanism for Hg enrichment in estuarine food chains. Given the quantity of moderately contaminated detritus freely accessible to the food chain in the harbour, Hg uptake probably occurred either through direct intake of contaminated detritus or by consumption of small contaminated benthic organisms by larger predators (magnification by the chain). The latter is probably the case as carnivorous fish have the highest concentrations regardless of whether they are pelagic or benthic feeders (Table 1).

Hg in fish is usually in the alkyl form. Unpublished work has indicated that only 9% Hg in organic-rich sediments and seagrass is alkyl-Hg. Given this low value and the fact that herbivorous/detritus feeding species contain less Hg, it is likely that uptake in fish is not directly via consumption of seagrass or detritus. The major difference between this system and other Hg-polluted systems may be that the seagrass meadows support Hg accumulating microfauna which methylate the Hg stored in the seagrass and make it readily available to their predators.

MANAGEMENT AND IMPLICATIONS

Defining the Problem

Since closure of the western end of Princess Royal Harbour in 1984 to fishing and taking of shellfish, the number of fish, shellfish and crustaceans have flourished. This suggests that levels of Hg in sediments have had little impact on numbers of biota. Hence the problem appears to be one of edible biota exceeding human health regulations and the closure of a fishing ground rather than an obvious ecological problem.

Monitoring to date indicates contamination of edible biota in the western end of the harbour may not naturally recede to an acceptable level for some years (MILLS, 1987). Pollution has occurred over about 30 years, and no single rapid, non-destructive, cost-effective management solution is readily apparent. There is therefore a need to find a combination of management methods which may accelerate the natural depuration process (MILLS, 1987).

Physical Removal of Organics

Management action directed at physical removal of fine organics or algae entails a risk

of losing seagrass as contaminated seagrass, algae and fine organic detritus are closely interspersed. Loss of seagrass is environmentally unacceptable, because recolonisation of resident *Posidonia* sp. is extremely slow (KIRKMAN, 1989), and because seagrass meadows provide a nursery for juvenile fish, shelter and habitat for many species of biota, and stabilize sediments. On the other hand, benthic algae are unattached and could be removed; they grow quickly and their communities are much less sensitive to direct physical disturbance.

Removal of benthic algae from the most contaminated area of Princess Royal Harbour, however, is not a cost-effective solution for the Hg problem: removal of 10^4 tonnes wet weight of algae would recover only about 1 kg Hg which represents <1% of Hg in the harbour (JACKSON *et al.*, 1986). Such an operation would not remove the more contaminated fine detritus, but may help to minimise macroalgal smothering of the seagrass meadows, which at present is implicated in the decline of these meadows: the harbour is eutrophic.

Weed and seagrass accumulation on the beaches could be removed as it is easily accessible. Although its removal would not remove much Hg, it could eliminate part of the contaminated food supply for cockles and hence reduce their Hg levels. In addition, it would help in reducing odour and improving aesthetics. Such a task could be carried out in a manner which would raise community awareness, interest and vigilance so that the potential for further pollution would be greatly minimised.

Resuspension of Organics Fine Sediment

An undesirable option would be to disturb and resuspend the fine organic sediments and algae in the most contaminated areas at times when dispersal by water movement was most likely. Apart from the risk of damaging seagrass, the risk of spreading contamination to less polluted areas is unwarranted.

Burial of Organic Matter

It was once proposed that a channel be dredged through the sand flats and a marina be built near the drain outlet. The dredged channel would supposedly cause better flushing and hence wash out the Hg quicker. The dredge

spoil was to be used to bury the most contaminated seagrass meadows. This proposal was rejected on the grounds that (a) lack of turbulent energy for resuspension of fine organic particles limited the export of Hg from the area, rather than the lack of water flushing (b) the seagrass meadows have ecological value and (c) dredging would be very expensive and would probably cause problems of light attenuation and sediment settlement on seagrass. In addition, the proposed marina would impede water movement, which tends to be parallel to the shore (*pers. obser.*).

Elimination of Cockles

The most highly contaminated cockles occur on the sand flats. For most of the tidal cycle this area is relatively dry. Surface-contaminated sediment could be turned over by ploughing up the top 12 cm. This would bury the contaminated cockles in a reducing environment where they would probably die and leave a relatively Hg-free oxidised surface sediment. In addition, it may help to release Hg which has been precipitated by low Eh conditions in the sediment profile. The next generation of cockles would be more likely to be less contaminated.

A better alternative would be to remove contaminated cockles either by hand collection or mechanical harvest. Such procedures could be relatively inexpensive if carried out on a community basis. Recolonization occurs rapidly (*pers. observ.*) so harvesting would not reduce the cockle population in the long term.

Suitability of Health Standards

NAGY and OLSON (1980) have noted that health limits differ across countries, and within States in Australia. A number of factors such as average daily seafood consumption and average body weight of citizens contribute to the determination of each nation's regulations and/or guidelines. Interestingly the national Australian standard is 0.5 mg kg⁻¹ wet weight, similar to that for Japan (0.4 mg kg⁻¹ wet weight; HANCOCK, 1982), yet the Australian diet and body weight differs considerably from Japanese. This standard could be regarded as being very conservative, given the history and attitude to Hg pollution in Japan. It is significant, however, that Japan has exempted fish species

such as shark and tuna (carnivorous species), which are stated to have naturally high levels of Hg, from its regulation (HANCOCK, 1982) without apparent human health problems.

In assessing the various health standards for Hg in fish in Australia, HANCOCK (1976 and 1982) in his review on acceptable levels of Hg in fish, indicated that the present standards were conservative and, questioning the method of deriving standards, sought "a fair deal for the fishing industry." GOLDWATER (1974) strongly questioned the scientific legitimacy and validity of the U.S. and Canadian standard, which is the same as that for Western Australia.

The incidence of Hg-contaminated fish having an adverse effect on humans in Minimata, Japan, occurred within a fishing community which lived on a staple diet of fish. The Hg-industrial discharge responsible, unlike most Hg discharges, contained the more toxic and rapidly bioaccumulated methyl-mercury form. There is no evidence that this occurred in Princess Royal Harbour: the effluent was derived from scrubbed gases evolved from the reaction of sulphuric acid with mineralised rock phosphate. Consequently, one management option would be to review the standard with a view to opening the harbour.

Taking No Action

The recovery and decontamination of estuaries with respect to Hg has been reviewed by CATO *et al.*, (1980). The best example of recovery was in the Ottawa River, Canada, where Hg contamination declined by about 40% and 66% yr⁻¹ in fine and coarse sediments respectively. This decline was attributed to natural mechanical transport by current action of contaminated coarse sediment and chemical desorption of Hg from fine sediments.

Generally, however, the literature indicates slow decline of Hg contamination in estuarine systems. Where Hg levels have declined, it was largely attributed to natural mechanical transport (current action) of contaminated sediment and accompanied by good flushing. The literature suggests, therefore, that chemical desorption of Hg from organic detritus in Princess Royal Harbour, and its ultimate export, would be very slow process.

The option to take no action is probably the

best option as the problem is contained and manageable at present. One environmental advantage derived from the closure of the fishing ground is that it stopped seagrass destruction due to netting. The author has observed seagrass being dislodged by nets trawled across the seagrass beds.

Declaring the Quarantine Area as a Marine Nature Reserve

This problem has provided a rare opportunity for a potentially harvestable resource to be protected and allowed to flourish naturally. The area could be declared a marine reserve for the purposes of recreation such as diving and study whilst at the same time be continually monitored as a classic case history. Such an approach would allow a rare opportunity to study the true dynamics of fish, shellfish and crusteans in a nursery area in inshore waters which would not be subjected to fishing.

Hg Discharge Management in General

This study shows that Hg discharge should be avoided, especially to areas containing organic-rich sediments, seagrass, algae, cockles, fish or fish nurseries, in particular those sustaining carnivorous species (and possibly benthic species). There should be no discharge to embayments with little turbulence and little net sediment transport out of the system even if flushing appears good. Where several types of discharge take place close by, discharges containing settleable organic waste should not be made near Hg discharge, especially in a passive system.

Whilst discharge to open coastal waters may have flushing advantages over discharge to sheltered areas and embayments, the author counsels caution. Levels of Hg in several species of fish at the top of the food chain in south-western Australian waters (CAPUTI *et al.*, 1979), north Australian waters (LYLE, 1984, 1986) and southern continental shelf of Australia (THOMPSON, 1985) exceed the NH&MRC standards for Hg in fish. This implies that the natural levels of Hg in unpolluted marine waters around Australia are too high, an observation which should discourage further discharge. Hence it is concluded that Hg dis-

charge into any type of coastal water around Australia should be considered conservatively.

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|| RESUMEN ||

El pequeño vertido de 14.2 kg Hg año⁻¹ que se ha realizado durante 30 años en el puerto de Princess Royal ha dado lugar a la detección de elevadas concentraciones de mercurio (0,01 a 7,6 mg kg⁻¹ wt húmeda) en la carne comestible de varias especies de peces, encontrándose valores muy elevados en el caso de especies carnívoras. Las concentraciones en los tejidos más blandos alcanzan de 2,2 a 50 mg kg⁻¹ wt húmedas. Estos valores son moderadamente elevados, sobrepasando el estándar sanitario australiano que está fijado en 0,5 mgHgkg⁻¹ wt húmeda, para alimentos (En la parte contaminada del puerto se ha prohibido la pesca). Los niveles de sedimentos son bajos en comparación con otros niveles mundiales, midiéndose un máximo de 2,2 mg kg⁻¹ wt seca, encontrado en una superficie sedimentaria de finos detritus a una distancia considerable de los vertidos. Los valores para sedimentos ricos en cuarzo (arenas) cerca del vertido son bastante bajos, con valores entre 0,04 y 0,11 mg kg⁻¹ wt seca, mostrando poca afinidad con el mercurio. A pesar de que la circulación de agua es buena y la velocidad de la misma llega a alcanzar los 0,5 ms.⁻¹ la ausencia de turbulencia permite la fijación de detritus contaminado de mercurio en praderas pantanosas y no debería permitirse sin tener en cuenta el sistema circulatorio del agua y la velocidad de la misma. Dada la elevada concentración de Hg en las especies marinas más grandes alrededor de Australia, debería suspenderse el vertido de Hg en las aguas costeras.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

Au port de Princesse Royale, une décharge mineure de Hg (14,2 kgHgr⁻¹ sur 30 ans s'est traduite par des niveaux de Hg compris entre 0,01 et 7,6 mgkg⁻¹ en poids sec dans la chair consommable de poisson. Ces fortes valeurs sont enregistrées chez les espèces carnivores. Les niveaux de Hg dans les coques (tous tissus mous) sont compris entre 2,2 et 50 mgkg⁻¹ de poids sec, ces valeurs sont modérément élevées et dépassent les normes australiennes de santé (0,5 mgHgkg⁻¹ de poids sec pour les produits alimentaires). La partie contaminée due port a été fermée à la pêche. Les niveaux enregistrés dans les sédiments sont faibles, comparés à l'échelle mondiale, avec une valeur maximale de 2,2 mgkg⁻¹ de poids sec que l'on trouve dans de fins sédiments de surface, riches en détritibus sur un herbier/un champ d'algues situé à une bonne distance de l'exutoire. Les teneurs des sables proches de celui-ci sont très faibles et comprises entre 0,04 et 0,11 mgkg⁻¹ de poids sec, ce qui indique une faible affinité pour le Hg. Lorsque l'effet de chasse est bon et que les vitesses de l'eau atteignent 0,5m⁻¹, l'absence de turbulence permet l'accumulation de détritibus contaminés sur les herbiers/champs d'algues qui agissent comme une trappe naturelle de particules surajoutées au Hg adsorbé. L'accumulation de Hg haut dans la chaîne alimentaire est probablement dû à la contamination algues/herbiers—détritibus qui sont une nurserie et une source d'alimentation pour les poissons et la faune benthique. Les résultats sont, discutés: remèdes et valeur naturelle de la zone contaminée, concordance avec les normes de santé et le contrôle des décharges à la mer.—*Catherine Bressolier, Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Eine relativ geringe Quecksilbereinspeisung (14,2 kgHga⁻¹) über 30 Jahre im Princess Royal Harbour resultiert in Quecksilbergehalten im Fleisch der Speisefische zwischen 0,01 und 7,6 mgkg⁻¹ Frischgewicht, mit den hohen Werten bei den gleichfressenden arten. Quecksilbergehalte im Muschelfleisch erreichen 2,2 bis 50 mgkg⁻¹. Diese Werte sind relativ hoch und übertreffen den australischen Gesundheitsstandard von 0,5 mgHgkg⁻¹ für Frischnahrungsmittel. Der kontaminierte Teil der Bucht ist allerdings für den Fischfang gesperrt. Die Gehalte im Sediment sind—im weltweiten Vergleich—niedrig, mit einem max. Wert von 2,2 mgkg⁻¹ Trockengewicht, gefunden im Oberflächen-Detritus einer Seegraswiese in relativ großer Entfernung von der Einleitungsstelle. Die Werte in quarzreichen Sanden sind selbst an der Einleitungsstelle gering (0,04–0,11 mgkg⁻¹), was auf deren geringe Affinität für Quecksilber hindeutet. Obwohl der Durchmischungszeitraum von 14 Tagen bei Strömungsgeschwindigkeiten von 0,5 ms⁻¹ recht gut ist, führt das Fehlen von Turbulenzen doch zu einer Anreicherung von quecksilber-kontaminierten Detritus in seine Graswiesen, welche als natürliche Sedimentfallen dienen. Die Akkumulation von Quecksilber in der Nahrungskette geht auch darauf zurück, daß die Detritus-/Seegrasgemeinschaft Brutplatz für Fische ist und gleichzeitig Nahrungsquelle für Rische und bodenbewohnende Organismen, die den Fischen als Nahrung diene. Die Ergebnisse werden diskutiert in bezug auf die Selbstheilung des Systems und den natürlichen Wert der belasteten Region, den Gesundheitsstandard und die Einleitungsmaßnahmen. Da die Abfuhr von kontaminierten Partikeln und Sediment gering ist, wird das Problem noch einige Zeit erhalten bleiben. Auch bei rascherem Wasseraustausch und höheren Strömungsgeschwindigkeiten sollte Quecksilber nicht eingeleitet werden, insbesondere wegen der Tatsache, daß in größeren marinen Organismen um Australien bereits hohe Quecksilberwerte festgestellt wurden.—*Dieter Kelleat, Essen, FRG.*